Document #1

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Re: Review of Idaho Power Company technical reports pertaining to the geomorphology and sediment transport in the Hells Canyon Reach of the Snake River (March 2002; FERC 1971; Technical Reports E.1-1 and E.1-2)

Dear Craig,

Accompanying this letter is my review of the completeness and technical adequacy of Idaho Power (IPC) Technical Reports E.1-1 and E.1-2 regarding the geomorphology and sediment transport in the Hells Canyon Reach of the Snake River. This review will address the specific questions posed by the Forest Service in their May 8, 2002 document (attached) as well as issues discussed during site visits and subsequent conversations. Please don't hesitate to contact me if you have any questions.

Sincerely,

Jim O'Connor

Review of Idaho Power Company technical reports pertaining to the geomorphology and sediment transport in the Hells Canyon Reach of the Snake River (March 2002; FERC 1971; Technical Reports E.1-1 and E.1-2);

Background:

The Hells Canyon Complex is a series of three hydropower dams on the Snake River owned and operated by Idaho Power Company. These three dams operate under a single license granted by the Federal Energy Regulatory Commission. This license (FERC No. 1971) expires July 2005 and Idaho Power Company is in the process of renewing their license. In support of their license renewal application, Idaho Power Company has conducted several studies on how natural and cultural resources have been affected by operations of the Hells Canyon Complex. Several of these reports specifically address effects of the complex on hydrology, geomorphology, and sediment transport in Hells Canyon. For these topics, the key area of interest is the Snake River and the adjacent valley bottom between Hells Canyon Dam at River Mile (RM 247) and the confluence with the Salmon River at RM 188, commonly termed the "Hells Canyon reach" because it bisects the Hells Canyon National Recreation Area. For this reach, the river is designated either "Wild" or "Scenic" and has highly valued recreational, cultural, and ecologic attributes.

Resource Issues under Consideration:

This review focuses on three primary issues of channel and floodplain geomorphology: erosion of sand bars on the channel margin; erosion of terraces and riparian areas; and the condition of in-channel spawning and rearing areas for fish. These issues affect recreational, cultural, and ecologic resources and are ones identified by participants in the relicensing process as resources perhaps affected by operation of the Hells Canyon Complex. These issues closely parallel the issues addressed by the Idaho Power in their technical reports (e.g., Technical Report E.1-1, pp. 12-16).

Materials Reviewed:

Two draft reports prepared by Idaho Power Company in March 2002 were reviewed in detail. Technical Report Appendix E.1-1, by Parkinson, et al., is titled "Sediment Transport, Supply and Stability in the Hells Canyon Reach of the Snake River." Technical Report Appendix E.1-2, by Miller et al., is titled "Geomorphology of the Hells Canyon Reach of the Snake River." Each of these reports is supported by several appendices, which were all inspected to varying degrees. Additionally, other reports and scientific literature were consulted as cited in the following comments. These materials were supplemented by site observations during Oct. 26-28, 1998, and August 8, 2002, and discussions with colleagues.

Structure of this Review

I have several general comments, reflecting on the general presentation and technical merits of the two major reports, as well as specific comments regarding details of the analysis procedures, results, and conclusions. The general comments cannot stand by themselves, but reflect my overall opinion on the technical merits of the reports based on issues identified in the specific comments that follow.

General Comments:

Both reports were well written and organized. Both reports summarize a tremendous amount of information about the geology, hydrology, geomorphology, and sediment transport of the Snake River, including basin-wide information as well as specific information pertinent to the Hells Canyon reach. Some of the information is derived from existing scientific literature and technical documents (such as the geological context), some is from existing data, but newly organized (such as basin hydrology and reservoir sediment retention), and some comes from new measurements and analysis.

Some impressive technical accomplishments underlie the presented material. Notable among these are the development of an integrated high-resolution topographic and bathymetric models (Butler, 2002) of the canyon bottom and river channel, detailed one-dimensional unsteady flow modeling of the entire study reach (Rungo, 2001), and digital grain-size analyses from underwater photography.

However, neither of the major technical reports would fare well in a rigorous scientific peer-review process. Issues of presentation include the considerable duplication and interdependence between the two main reports (E.1-1 and E.1-2). The information could have been much more efficiently presented if combined into a single report. I found myself continuously going back and forth between the two reports to establish connections between observations and conclusions developed between the two reports. Also, much of the presented information was not particularly germane to the issues, and could have been more succinctly referenced, thus focusing discussion on the topics of immediate interest. Many of the figures were poorly designed or not very legible, and did not convey their intended points. Some sections and figures were missing or not yet completed.

More substantive scientific issues also mar the reports. Both reports seemingly have a clear agenda--to show that the Hells Canyon Complex has had little effect on downstream hydrology, geomorphology, and sediment transport. In developing these conclusions, the reports fail to completely address some key issues, in many cases do not reasonably link observations to interpretations, fail to test results and hypotheses (either through sensitivity analyses, statistical testing, or additional measurements), and rely on untestable suppositions or assumptions. Most of these issues will be discussed in the specific comments that follow.

Three major shortcomings of the reports bear mentioning in these general comments:

1. The lack of a complete and comprehensible sediment budget. An important potential effect of the Hells Canyon Complex on downstream alluvial features and channel substrate is the trapping of upstream-derived sediment in all three project reservoirs. Aspects of a sediment budget are presented, including estimates of sediment coming into Brownlee Reservoir and the volume of sediment delivered by tributaries into the Hells Canyon reach downstream of the Hells Canyon Complex. From this, the reports conclude that the volume of this trapped sediment is insignificant compared to the sediment introduced to the channel downstream of Hells Canyon Dam. While this may be true for certain ranges of clast sizes, the presented information does not fully support this inference. As more fully discussed in the specific comments, details of how the sediment volumes (and component grain sizes) in Brownlee Reservoir were measured and totaled are not clearly presented. In addition, the sediment sampling strategy deployed in the reservoir is not likely to provide a complete accounting of the sediment sizes. Moreover, no sediment volume estimates were presented for sediment accumulating in the reservoirs behind Oxbow and Hells Canyon Dams. Explicit quantification of these volumes is critically important because this sediment would have been delivered to the mainstem Snake River close to the area of interest, and is likely to be composed of a range of grain sizes relevant to all the major geomorphic issues in the Hells Canyon reach. Estimates of sediment volumes in these reservoirs could serve to check or calibrate estimates of local tributary sediment delivery into the Hells Canyon reach downstream of the dam complex. The sediment delivery estimates from the tributaries into the Hells Canyon reach, calculated to be more than15.1 million tons per year on basis of tributary sediment transport capacity (16.7 million tons per year when extrapolated to include hillslopes directly contributing to the Snake River), are extremely high relative to other measured values in the literature, especially from largely natural landscapes such as the Hells Canyon National Recreation Area. Considering the width and length of the Snake River channel in the Hells Canyon reach, these estimated tributary sediment inputs would have filled the channel with more than 40 meters of sediment in the time since impoundment. This is not a very plausible result, especially in light of other analyses indicating that the channel is stable with very limited sediment transport.

2. The lack of adequate empirical analyses of potential downstream effects of the Hells Canyon Dam complex. Dams affect channels downstream by altering the flux of sediment, water, and organic materials. Major downstream morphologic effects on many dammed rivers are changes in channel geometry, channel substrate characteristics, and patterns of erosion and deposition (e.g. Williams and Wolman, 1984; Collier et al., 1996). Previous studies on many rivers, including the Snake River in Hells Canyon (Grams, 1991; Schmidt et al., 1995; Grams and Schmidt, 1999), have shown changes to channel and valley bottom attributes that decrease in magnitude with distance downstream of the dams. In some cases, it is evident that changes commenced after emplacement of the dams. While this evidence is empirical, it is strong evidence for changes to channel and valley-bottom characteristics attributable to changes to the system imposed by the dams. For the case of the Hells Canyon reach, downstream changes to sand bar conditions (volume, area, distribution) and channel substrate characteristics (bed material size, armouring) would be important components of an analysis evaluating the effects of Hells Canyon dam on downstream resources. The Idaho Power Company analyses of sand bars focused on the time primarily prior to dam closure (historical photo analysis), and the last 5 years (perhaps after the period of major adjustment). A complete aerial photo analysis of the sand bars, coupled with the available survey data (from Idaho Power studies and those of Grams and Schmidt) is sorely needed to document changes to sand bars for the period prior to impoundment to present. This analysis should follow the lead of Grams (1991) and evaluate changes with respect to time, distance from Hells Canyon dam, and type of sediment accumulation. Estimates of the volumes and grain sizes are needed so that this information can be evaluated in light of realistic sediment budgets. Only with this empirical evidence in hand and coherently presented, can hypotheses about sand bar dynamics and their relation to floods, upper basin activities, sediment trapping, and dam construction be reasonably addressed and supported. Likewise, channel substrate conditions should be sampled in order to specifically test the hypothesis that channel armouring and bed sediment size decrease downstream from the dam, thus indicating that impoundment has altered bed texture. The reported data on substrate textures are not presented so that this hypothesis can be tested, and it is not clear that the bed was sampled in such a manner that the collected data would be sufficient to evaluate this hypothesis.

3. There is no discussion of the effects of flow ramping. The reports include no analysis of the possible effects of daily flow ramping on channel and channel margin features in the Hells Canyon reach. The presented analysis of changes in flow conditions, using daily mean values, completely sidesteps daily fluctuations of up to several hundred m^3/s, resulting in daily stage fluctuations locally greater than 0.5 m. For some channel and valley-bottom features, these fluctuations may trigger local erosion and deposition such as they have for the beaches along the Colorado River in Grand Canyon. My suspicion is that flow ramping presently has little effect on Hells Canyon beaches because of the generally gently sloping faces of most of the sand deposits, but this is an aspect of the system that should be quantitatively assessed, both for possible geomorphic effects as well as for possible effects to fish use and stranding. The information to do such an analysis is apparently available. Channel and valley-bottom features have all been comprehensively mapped, and the high-resolution topography and 1-d flow modeling can be used provide estimates of the areas inundated and exposed for various ramping scenarios.

<u>Specific Comments:</u>

Geomorphology of the Hells Canyon Reach of the Snake River [Technical Report appendix E.1-2]

1. p. 1-11, third paragraph. The Pierce and Scott (1982) quote of “sustained seasonal flows probably at least ten times larger than discharges of present streams” is alluded to several times in both reports as evidence that flows of the Snake River in Hells Canyon were at least ten times larger during the Pleistocene. This is a speculation that has no quantitative basis either at the original study sites of Pierce and Scott, or several hundred kilometers downstream in Hells Canyon. Seasonal and peak flows were likely higher in Hells Canyon, but there is no real evidence presented that they were tens time higher.
2. p. 1-13,14, section 1.4.3. Most geologists and climatologists believe that climate changed quite abruptly (over decades to centuries) from Pleistocene glacial conditions to warmer Holocene conditions, and that Holocene climate conditions have *not* become “gradually warmer.” There certainly have been fluctuations in the Holocene and these fluctuations have likely been important in creating some of the terraces and fans flanking the channel, but no real information is presented on how these Holocene features relate to Holocene climate conditions and consequent changes to hillslope and sediment delivery processes.
3. Section 2.1. Documentation of historical land-use activities such as trapping, timber harvest, mining, etc., is seemingly intended to bolster the hypothesis that these factors produced “a ‘slug’ of sediment that worked its way through the system but has likely mostly disappeared.” While this is a plausible hypothesis, it is completely unsupported by the presented data, which consists of anecdotal accounts, speculations based on observations from other basins, and isolated measurements (and graphs such as figure 2.1 which have no information regarding their sources). There is no actual data presented for elevated sediment loads in the Hells Canyon reach nor is there presented evidence for geomorphic consequences of such elevated sediment loads. Additionally, recent research is showing that sediment produced from landscape disturbance does not move as a “wave” through the system, but instead disperses and diffuses as it moves downstream (e.g., Sutherland et al., 2002). The concept of a sediment wave moving through the Hells

Canyon reach (and producing larger sand bars during the time prior to impoundment) is speculative and completely unsupported.

4. Section 2.2. It is true that the volume of water stored and the contributing area of sediment supply now not delivering sediment to the Hells Canyon reach is small compared to the areas subject flow regulation and sediment trapping by upstream and earlier projects, but describing this in terms of percentages obscures the magnitudes of sediment and water involved. It is the magnitude of fluxes of sediment and water affected that affects conditions in the downstream reach, not the percentage change. For example, from the drainage basin values given in this section, the HCC cuts off sediment from 4100 mi^2. The *volume* of sediment produced from this area is the critical value, not the oft-stated fact that it represents only 5.5% of the total basin area. (It is not mentioned, however, that these 4100 mi^2 represented 30% of the remaining area contributing sediment to the Hells Canyon reach.)
5. Section 3.2. This section on climate and effects on discharge is highly speculative, especially inferences regarding Holocene climate conditions. Additionally, the statement that "Global and regional climate conditions during the last 1000 years are believed to have been relatively similar to the present regime" is surprising given the abundant evidence for the Little Ice Age—generally regarded as the coldest period of the Holocene--culminating in the 19th century. The postulated effects on discharge and sediment transport in Hells Canyon are also highly speculative and not based on any apparent quantitative or empirical analysis.
6. Section 4. This section could be made much more comprehensible if the sediment dynamics were presented independently from the comments regarding river morphology and classification, which have little pertinence to the critical issues. Additionally, some simple diagrams should be constructed illustrating *measured* sediment and water fluxes into the HCC (and their uncertainties). The sediment fluxes should be separated by component grain sizes. This type of diagram could readily convey to the reader both the absolute magnitude of project effects and well as the relative magnitudes in comparison to sediment trapping by upstream reservoirs. As presently presented, the sediment budget for sediment coming into the project area is nearly incomprehensible. Such diagrams would point out unmentioned inconsistencies such as the discrepancy between the 503 acre-feet/yr of sediment measured at Weiser (equivalent to a total volume of about 20,000 acre-feet of sediment over the project lifetime) with the 62,000 acre-feet measured in Brownlee Reservoir.
7. The inference of little bedload transport drawn from the observation of little net aggradation at the Weiser gage site is incorrect. All that can be assumed is that the volume of sediment transported to Weiser is equivalent to that transported away, and that the river is "graded" (Mackin, 1948). Evidence of lateral channel migration at the gage site indicates that there indeed has been substantial bedload transport. Measurements of such shifting could be used to determine morphometric estimates of bedload transport rates in this reach (McLean and Church, 1999).
8. p. 4-17, 2nd para. It is true that the coarse bedload in the Hells Canyon reach is not likely derived from the sand and small gravel transported through the Weiser reach. But this conclusion sidesteps the more likely scenario that components of the bedload moving through the lower gradient Weiser reach become an important component of the *suspended* load in the Hells Canyon reach because of the greater slope and confinement

of the channel in Hells Canyon. This is another case where the sediment dynamics have been obfuscated by terminology usage, and could have be more clearly presented by focusing on the fluxes of grain sizes, regardless of transport mechanism.

9. Section 4.2.3, introductory para. As stated in comment 3, the speculation (now stated as "likely") that "elevated loads of fine materials from anthropogenic disturbances were likely washed through this reach into Hells Canyon" is highly speculative and unfounded.

10. Section 4.2.3.1. Very little information is presented on how the total sediment volume in Brownlee Reservoir was determined aside from it being the result of bathymetric surveys and comparison with pre-project topography. No information is given on the accuracy of the bathymetry or the accuracy of the original topography. Especially important for understanding the sediment budget and its uncertainties would be careful analysis of the uncertainties in the estimate of sediment in Brownlee Reservoir.

11. Section 4.2.3.1. The sampling strategy employed for determining overall sediment composition is probably not adequate. By only sampling the delta and thalweg, the sediment entering from side tributaries is not included in the characterization.

12. Section 4.2.3.2. Oxbow and Hells Canyon Reservoirs. Not determining the sediment volumes in these two reservoirs is a critical shortcoming of the IPC studies. Information on the sediment coming into these reservoirs could be used to either develop empirical sediment delivery estimates from local tributaries (e.g. O'Connor et al., 2001, in press) or check the capacity-based measurements summarized in section 5. Although the original 20-ft contour interval topographic maps are understandably not of sufficient precision to resolve reservoir sedimentation, construction new topographic maps of pre-project topography with appropriate resolution could be done from pre-project aerial photographs and would serve as a basis for comparing modern bathymetric measurements.

13. p. 4-22. It is not clear how excessive sediment delivery from a single event on Pine Creek "confirms" that "negligible sediment supply appears to be currently available from Pine Creek for events with less than a 100-year return period."

14. Section 4.2.3.3. The report relies on comparing the unverified estimate of 16.6 million tons/yr coming into Hells Canyon below HCC to a partial but measured volume of 2.78 million tons/year into Brownlee to conclude that the HCC has little effect on overall sediment transport through the Hells Canyon reach. But this comparison is of estimates derived from very different methods, both with large and uncharacterized uncertainties. While the capacity-based method is highly suspect, at least a more fair comparison would be to apply it also to the landscape above HCC—including all the local tributaries draining into the three reservoirs. I would anticipate two results. One would be that that the difference between the volumes of sediment entering the river below and above Hells Canyon Dam would diminish, and two, the calculated volumes into Brownlee Reservoir would completely out of line with the measured sediment accumulation rate determined from the bathymetric survey.

15. p. 4-22, section 4.2.3.4. I don't see how these reported volumes of component grain sizes were determined from the data presented in this report or in IPC 2001a. Of the total annual flux of 1550 acre-feet of sediment, it is reported that 97 acre-feet is "fine sand" and 59 acre-feet is "very fine sand." However, the three deep cores have an average of 26.3 percent very fine sand, which would imply more than 400 acre-feet of very fine sand. Likewise, the "upper reservoir" samples average 20% very fine sand and coarser, indicating about 450 acre-feet of sand. Some additional information on how the reported values of sediment volumes and their component grain sizes were derived is necessary to resolve the apparent discrepancy with the reported data.

16. p. 4-22, section 4.2.3.4. It is not clear why the "very fine sand" is combined with "silt" for purposes of discussing project effects. As shown in figs. 14-17 of *Sediment Transport, Supply and Stability…*, very fine sand composes up to 15% of the sand bars, and I suspect an even larger percentage of some of the eroding "terraces" that flank the channel.

17. Section 5.1. Stream flows. The magnitude and effects of flow ramping are not mentioned.

18. Section 5.1.2. A table showing how specific instantaneous peaks have been affected by storage in the HCC complex would provide specific information on how flow conditions important to channel morphology have been affected in the Hells Canyon reach. The presented information of the Grams Analysis and the Indicators of Hydrologic Alteration analysis provide general information on the overall effects of the complex, but provide little information on specific changes to large peaks.

19. Section 5.2.2.2.4 and fig. 5.11. To my eye the bedrock pools appear deeper. But this brings up a more important point applicable to all analyses in both reports—it is stated that there are no significant trends or differences among the pool classes. But no indication of actual statistical testing is provided, giving the impression that this is an ad hoc interpretation rather than an outcome of statistically based hypothesis testing. This type of loose language and linking of observation to conclusion permeates both reports, severely weakening most points.

20. Section 5.3.1.1.1. Short-term quantitative sediment yield estimates. The capacity based estimates of 28,100 tons/mi^2 /yr of sediment produced by local tributaries into the Snake River is remarkably high. The only measurements in the literature that approach these values are from small areas of exceptionally disturbed or barren landscapes. None are comparable to the largely natural (or natural like) Hells Canyon area. I suspect that natural sediment delivery rates are at least an order of magnitude lower than those calculated here. The proposed sedimentation rate would equate to nearly 500 million tons over the period 1968-2000, or 4.5×10^{11} kg. Assuming a density of 1500 kg/m^3 leads to a total volume of 3×10^8 of sediment. Considering that the mean channel width is about 75 m and the mean valley-bottom width is about 130 m and the overall length of the study reach is about 100 km, this volume would result in nearly 25 m of aggradation if spread over the entire valley bottom, or more than 40 m of aggradation if just spread over just the channel. That is a lot of sediment.

21. Section 5.3.1.1.2. Long-term sediment yield considerations. The inferences and conclusions in this section are not based on any relevant data and are highly speculative. Moreover, this text seems to be making the point that sediment delivery from the tributaries to the Snake River is hindered by tributary geometry.

22. Section 5.3.1.2.1. Short-term quantitative sediment yield estimates (from hillslopes). Extrapolating the capacity-based measurements from the tributaries to estimate sediment production from hillslopes is not appropriate. Foremost, more than 62 percent of the area has slopes greater than 40%. These slopes are steeper than the angle of repose and are not likely to be "transport limited"—a key assumption intrinsic to the capacity-based transport analysis.

23. P. 5-20, Rock Varnish. No source is provided for the quote providing quantitative information on the rate of rock varnish formation in Hells Canyon.

24. Section 5.3.1.3. Riverbed materials. If the incipient motion results indicate only pockets of bed material move under the flows currently experienced in this reach, then what has happened to the more than 15 million tons of sediment that has been delivered by the tributaries? This seems like a fundamental inconsistency between the sediment delivery analysis and the riverbed mobility analysis.

25. Section 5.3.1.3. No reference is provided for the statement relating groves to long periods of contact time under conducive weathering conditions.

26. Section 5.3.1.3. p. 5-23. The apparent stability of the USGS cross sections only implies no net aggradation or incision. (See comment 7).

27. Section 5.3.1.5. Visual Analysis of Bed Materials. It is not surprising the bed samples are from local sources, given that upstream sources have been blocked. The science underlying this section is weak compared to standard petrographic sampling and analysis techniques (Folk, 1980). Samples "believed to be representative" were selected. Only hand lens identification of minerals were conducted. And there was no systematic comparison with tributary sediment or upstream sediment so as to conclude where bed material was derived. Although I do not doubt that most of the bed material in Hells Canyon is locally derived, the process for documenting this could have been much stronger. Comparisons of pre-project (from geologic exposures) vs. post-project bed material would have been most convincing analysis.

28. Section 5.3.2.1. The presence of Bonneville flood sediment (at the base of the large bars) near present river level at several places indicates the pre-flood river level was very close to the present river level, and that there has been little, if any, downcutting over the last 14,500 years.

29. Section 5.3.2.1. The conclusion that the "transport capacity of the mainstem appears to have been so effective that the enormous volumes of sediment produced by local sources [here stated to be a *minimum* of 16.6 million tons/year] have not been sufficient to preclude this downcutting" is seemingly inconsistent with the analysis indicating that bed sediment is *not* moving in the channel. Is all of this tributary sediment moving as suspended load? This needs clarification.

30. Section 5.3.2.1. The "Buffington analysis" of grain size, mobility, and sediment supply is missing.

31. Section 5.3.2.2.1. Left out of this summary of Grams' analysis is his observation that the magnitude of post-HCC change in sand bar frequency and size decreases downstream from the dams. This is strong empirical evidence that the dams are related to the changes in sand bar size and abundance. Discounting this evidence either requires alternative explanations supported by data, or alternative analysis showing that Grams' results are in error. The provided analyses of sand bar changes over the last 4 years (1998-2001) and the period prior to 1968 completely misses the period of maximum expected (and observed) change during the first couple decades after the 1967 closure of Hells Canyon dam.

32. p. 5-31, physical surveys. The size range of <0.074 mm also includes very fine sand in addition to silt and clay. It is not clear why this size criterion is used, since it is inconsistent with the particle size data provided most of the other particle size analyses provided in the technical reports.

33. p. 5-33, physical surveys. The broad conclusion that the sand bars are dynamic features is probably accurate, but it does not necessarily follow that that the dynamic range will not change is sediment supply changes. This is another case where the IPC analyses have completely sidestepped the overall issue—the perceived (well, actually, documented) diminishment of sand bars since completion of the HCC. What is sorely needed is a complete and quantitative survey of sand bar changes before and after completion of HCC, so that temporal and spatial trends can be identified and quantified. Especially valuable would be information on the *volumes* of sand involved. Only with this information, can supportable inferences regarding causes of sand bar changes be discussed. Furthermore, this information could provide the basis for developing mitigation strategies.

34. p. 5-34, aerial photograph analyses. This analysis should have been conducted for the entire post-HCC period as well as the pre-HCC period. The question is not whether or not the sand bars are dynamic features, which seems to be the overall conclusion, but whether the dynamics have been altered by HCC operations. This question is not specifically tested by either the limited physical surveys or the limited aerial photograph analysis.

35. Section 6. This section selectively uses the literature and inferences developed from previous sections of this report to make the case that "the direct effects on channel morphology downtream from the HCC appear to minimal…" But most of the literature references are inappropriate for the situation, and many of the inferences, as noted in previous comments are highly speculative and not adequately supported by the presented data.

36. Section 6.1, p. 6-3. The inference that "significantly higher paleo-discharges very likely transported larger volumes and sizes" is not supported by independent evidence of larger discharges (aside from the Bonneville flood) nor are features attributed to these higher discharges identified.

37. Section 6.1, p. 6-3. The inference that "anthropogenic disturbances…caused an increase in sediment supplies to the system as a whole" is highly speculative and unsupported by actual data for the Hells Canyon reach or anywhere else on the Snake River.

38. Section 6.1, p. 6-3. The comparison of the upstream quantity of sediment delivered to HCC to the sediment delivered to the Hells Canyon reach by tributaries is clouded by the implausible tributary delivery rates and the lack of complete analysis of the sediment residing in the three reservoirs. The estimate of "a minimum of 16.6 million tons of material annually" delivered to the Hells Canyon reach does not make sense in light of other measured sediment delivery rates as well as the absence of evidence for this sediment in the Snake River channel. The idea that a significant portion of this sediment is stored in tributary bends is not a realistic scenario given the volume of sediment involved. If sediment is stored in tributary bends, then it does not contribute to features in and flanking the main channel.

39. Section 6.1, p. 6-4. The discussion of the armoured channel bed and the source and age of the constituent materials is highly speculative. Relating the armoured bed to a presumably distinct hydrologic regime would plausible if there were indeed evidence for a distinct hydrologic regime and it could be shown that the bed was deposited during that time, but no real evidence of either type is presented.

40. The analysis of material composition does *not* show in any rigorous manner that upstream sources are not a constituent of the bed material. The presented analyses only characterized the modern channel bed material and it is not clear that the sampling or analysis methods were appropriate to determine differences in sources areas.

41. Section 6.1, p. 6-4. A key hypothesis is presented here... "if the HCC were responsible for the armouring observed in Hells Canyon, then this process would be progressing in a downstream direction from immediately below Hells Canyon Dam and the grain size distribution would be expected to become finer in the downsteam direction…" The report states that "in fact the channel bed is well armoured from just below Hells Canyon Dam to below the Salmon River, with no clear downstream trend in either armouring rations of finer grain sizes." This is an important conclusion. But no data or analysis is presented to substantiate it.

Sediment Transport, Supply and Stability in the Hells Canyon Reach of the Snake River [Technical Report appendix E.1-1]

1. Because of the substantial overlap between reports, many of the comments regarding the geomorphology report are applicable to this report as well.
2. Executive Summary, p. 5. It is not clear to me why the original hypothesis that "there would be little, any, bed-material transport within the mainstem Snake River in the Hells Canyon reach, with or without the influence of the HCC" and the factors leading to IPC to promote this hypothesis "preclude the more typical approach of a sediment budget type of study." The uniqueness of the Hells Canyon reach (and I believe it is unique relative to many dammed rivers) would seem to especially merit a complete sediment budget so that the sources and fluxes of sediment (and grain-size of components) could be rigorously identified. Many of the critical issues revolve around sediment flux and storage processes.
3. Section 3, p. 13. The report states that there is a "general perception" that sandbar areas are declining. This statement ignores that this finding of declining sand bars (and the underlying data) has appeared in at least two peer-reviewed scientific publications (Schmidt et al., 1995; Collier et al, 1996).
4. Section 5.1.1. Aerial photographs of sandbars; p. 18. No clarification is offered as to why photographs subsequent to 1968 were not used for analysis of sand bar changes. I doubt that no suitable post-191 photos were available.
5. Section 6.2.2. Mainstem bedload measurements, p. 28. Apparently, there was only one attempt at actual bedload measurements in the main channel, at an unspecified location and flow. For an issue of such importance, it seems that a more vigorous program of mainstem bedload measurements would be appropriate. A systematic bedload measurement program, besides being the best test for the hypothesis that there is little bedload transport, would serve to calibrate transport models useful for testing how past and future operations might affect bedload transport. After reading statements in the preface, such as "the most effective description of a natural system generally depends on empirical data collected from that specific system," I expected much more of this type of actual measurement data.
6. Section 6.4.1. Sandbars, p. 31. It is important to note that all the sandbar surveys used in the quantitative analysis of sandbar changes were conducted after the two large flows of 1997. Consequently, these surveys will not capture the effects of the floods, which is probably the time of most pronounced and persistent change.
7. Section 9; Calculation and analysis methodology. Long and detailed descriptions are provided for calculating "flow resistance" (p. 40-46), "incipient motion" (p. 50-60) and

"transport capacity" (p. 60-65). But in the end of each of these sections, a seemingly *ad hoc* choice of relationship was used for a predicting conditions in Hells Canyon. For example, the Mussetter equation was used for calculating flow resistance on the basis of "*engineering judgement and reasonableness of results*" and undocumented comparisons between calculated and observed flow conditions. Incipient motion was judged to relate to a Shield critical dimensionless shear stress value of 0.047 (p. 59), apparently on the basis of Gessler's (1971) results (p. 52), but with no acknowledgement of the intervening 7 pages of discussions of uncertainties and possible modifications. For tributary transport capacity, IPC used the Schoklitsch equation, which "*yielded values that were, for most discharges, between the values predicted by the other equations.*" In none of these cases, are there comparisons of predictions derived from these equations with measured data from the study area, or are there sensitivity tests using reasonable ranges of parameters (or alternative relations). The reader is not provided with any sense of the sensitivity or accuracy of the predicted values.

8. Section 9.4. Calculation of Armor Formation. The point of this section is not clear. The conclusion seems to be that the mainstem channel is not "ultimately armoured" given the grain size distributions of the bed and subsurface. How this relates to the HCC is unclear. What seems to be missing here is any kind of temporal or longitudinal analysis of armouring. In Hells Canyon, where there is unlikely to be any prior data on substrate, a longitudinal analysis of armouring could indicate if the HCC has led to substrate coarsening.

9. Section 9.4.2. Armoring in the mainstem Snake River, p. 49. Here it is stated that incipient motion computations for the existing armor layer are based on the d_{84} particle size in the surface layer, "based on the assumption that at least 16% of the larger particle sizes in the surface layer would need to be immobile to provide sufficient material for a limiting armor layer to develop." This may be true, but this does not mean that transport will not occur at lower flow strengths, such as for incipient motion computations based on d_{50}. Use of some sort of mean or median particle size is the usual case for calculating incipient motion (e.g. Buffington and Montgomery, 1997). Using d_{84} in calculating the critical dimensionless shear stress (eqn 31, p. 59), as was the case for the incipient motion studies presented here, may result in unrealistically high critical shear stress values for initial motion, since critical shear in the Shields relationship is directly proportional to the grain-size scaling. I was going to investigate the effect of this substitution, but could find no actual grain size data for the mainstem Snake River besides the difficult-to-read plots of figs. 72 and 73. The report does state, however, that "there is actually little difference between using the d_{84} aparitcle size in the surface layer and the d_{50} particle size…" Although, this difference is not quantitatively described.

10. Sections 9.5. Calculations of incipient motion. I see several problems with the way this analysis was conducted. From the description of the analysis, a cross-section average value of boundary shear was calculated for each cross section. Actual shear values likely vary by a factor of two more across each cross section. Even substituting local depth into the shear stress calculation would have provided a better characterization of boundary shear across each cross section. Then, this average value of shear was compared to critical dimensionless shear value of 0.047 based on eqn 31 from a measurement of substrate (or sometimes an average of measurements) at the "nearest the cross section." As mentioned in the previous comment, using d_{84} will result in a higher calculated critical shear than would be typically calculated for a particular substrate composition. Additionally, there is no information on degree of fidelity between the measured particle size distribution at the sample site and the actual particle size distribution at the cross section site of calculated boundary shear. All of these aspects could and should be subject to sensitivity analysis. Perhaps these issues don't matter and the bed is indeed calculated to be everywhere stable for the entire range of plausible relations and parameter values. Alternatively, other equally plausible sediment transport relations or parameter values could result in calculations indicating the much of bed is indeed mobile for modern flows.

11. Sections 9.5. Calculations of incipient motion. Pool reaches and rapids were considered stable no matter the outcome of the calculations. Why not rely on the model for these parts of the channel? If inappropriate at pools and rapids, what makes the model more appropriate or the other types of channel segments. Reading between the lines, I suspect that the model predicted transport in the pools at some flows. This may actually be a reasonable result, but the seemingly ad hoc reclassification of pools as everywhere stable reduces the opportunities for insights into how the system operates. No information is presented on how many reaches were reclassified and what percent of the total reach they represent, so it is not clear for which parts of the river the calculations actually apply. The accompanying maps are incomplete and difficult to read.

12. Section 9.7.1. Estimation of sediment supply to the Snake River. Previous comments have noted the implausible implications of the very high estimates of sediment supply to the mainstem Snake River from tributaries downstream of HCC. The root of these extremely high estimates is the deductive "capacity-based" approach in which the theoretical sediment carrying "capacity" of the streams is integrated over the plausible range of flows for each tributary and summed (and then extrapolated) for the entire contributing area. I don't believe that this is an appropriate approach partly because I don't think that "stream capacity" is a valid concept. In reality (and in Hells Canyon), there is a complete spectrum of granular sediment and water mixture flows, ranging from dry ravel to sediment-free water flow. Capacity implies that water flows have a finite volume of sediment that they can carry depending of flow and hydraulic conditions. But this conceptual issue is not the source of the high estimates—it is the implicit assumption in these capacity-based relations that there is an unlimited sediment supply available for stream transport. In other words, all the sediment that could be picked up by the flow is ready and waiting. For these types of relations and results to even be plausible, Hells Canyon would be necessarily be composed of immense and steep mounds of unconsolidated sand and gravel, dissected by a dense network of rills, gullies and streams delivering sediment to the modeled location. My guess is that actual sediment delivery rates from the tributaries are an order of magnitude less than those predicted by IPC's capacity-based calculations. The only practical way to estimate sediment production rates from a landscape like this is through some sort of empirical analysis based on actual measurements of sediment yield. In some situations, sediment yield data can be related to landscape conditions within a GIS to develop realistic regional estimates of sediment production (e.g. O'Connor et al., 2001, in press). Sediment accumulation data from the Hells Canyon and Oxbow Reservoirs could aid this type of analysis.

13. Section 9.7.3. Reference values for sediment yield. The sediment yield values reported here are from select study sites, mostly representing highly disturbed landscapes. Not included are much broader and possibly more applicable measurements from around the Pacific Northwest, such as and Larson and Sidle (1980). Also, measured values of sediment yield typically scale with drainage area (e.g. Vanoni, 1975, p. 462). So ideally, calculated tributary sediment yields should be compared against a more complete set of reference values on a plot of catchment area vs. annual unit sediment yield. Comparison of the IPC calculated sediment yields with regression-based yields, such as those in Milliman and Syvitiski (1992) would also help in evaluating the reasonableness of the IPC estimates.

14. Section 9.7.4. Measured quantities of sediment yield from tributaries. Why are these values not reported and compared to the predicted values?

15. Section 9.10. Changes in sandbars based on analysis of aerial photographs. As mentioned in previous comments, this analysis is weak, not because of the methods, which seem mostly appropriate, but because only four sand bars were quantitatively evaluated and only for a period primarily before effects of the project would have likely affected the sand bars.

16. Section 10.1. Results and conclusions--sandbars. It is difficult to evaluate comparisons of the grain-size compositions between the sandbars and the Brownlee Reservoir sediment because of the apparently different size analysis procedures. Additionally, as mentioned in previous comments, it is difficult to reconcile the actual measurements of Brownlee sediment with the statement that "less than 4% are larger than fine sand." Moreover, it is not the percentages that are important, but the volumes. What is the *volume* of sediment in Brownlee that is of similar size to the sediment in the sand bars, and how does that volume compare to the volume of the sandbars, and to the volume that has apparently been lost from the sandbars since closure?

17. Section 10.1.2.3. Pine Bar. Transects A, B, and C seem to show systematic erosion. The claimed deposition of 1.5 ft is not evident in figure 18.

18. Section 10.1.2.3. Most other bars also show erosion between most periods. China Bar shows erosion and movement of sand down to the 30,000 cfs level.

19. Section 10.1.3. Area measurements (of historic photos). The statement is made that "in many cases, the area of the sandbars increased from a pre-dam period (1948) to a post-dam period (1964). Without error analysis, it is difficult to determine if these changes are significant. Moreover, stating that the 1964 photos represent a post-dam period is quite a stretch. Hells Canyon dam, the most proximal structure, was closed in 1967. The other, upstream, dams were closed only a few years before 1964, so it is unlikely that effects from those dams had materialized in Hells Canyon by 1964..

20. Section 10.1.4. Plan dimensional analysis. "no consistent trend" is reported, but this conclusion is difficult to substantiate because no data are provided.

21. Section 10.2.1. USGS Gauge (sic) analysis. The presented analysis is of limited utility. USGS gage locations are generally selected for stability. Only four cross sections are plotted, and they are all from after installation of the HCC. Additionally, not enough data are portrayed or analysis conducted to evaluate whether or not there is transport through the section. Nevertheless, changes of "2-3 ft" do indicate that sediment is moving through the system. Key questions include "are there changes in the cross section, even if slight, accompanying large flows?" and "what size flows trigger changes in bed elevation?" Answers to these questions could help in evaluating the incipient motions calculations.

22. Section 10.2.3. Incipient motion calculations. The conclusion that the "majority of the bed appears to be stable" must be viewed as quite tentative, given the uncertainities and assumptions in the analysis. A good part, perhaps a majority, of the bed (pools and rapids) was deemed stable in lieu of analysis. Empirical data (even such primitive tools such as scour chains and marked rocks would provide valuable information) and more careful analysis (in which local flow conditions were compared to local grain-size distributions) are sorely needed to be performed before determining that the channel is indeed stable and, as postulated, a relic of previous climate and flow conditions. How the bed could be stable for the last 1000 years, but everywhere accommodated more than 40 m of sediment from the tributaries is a still question needing resolution.

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Review questions posed by U.S. Forest Service, in their May 8, 2002 draft document outlining Hells Canyon geomorphology concerns.

Geomorphic Review Questions

1. Is the effect of the HCC project on resources of concern adequately addressed? (i.e. are the effects of current and proposed ramping rates on beach erosion addressed and is the resulting conclusion accurate?).
2. There is concern that the reports focus on the "Big Picture" (i.e. the geologic factors which formed the Canyon) tends to minimize and obscure potential project-related effects such as beach erosion.
3. Is the method for determining influx of sediment into Brownlee adequate given that there is no analysis of bedload movement and no sediment budget was constructed above and below the project.
4. Are conclusions in the documents accurate for identifying sediment transport flows and the lack of bedload movement upstream from Brownlee Reservoir?
5. In general, are the equations and analysis used in the IPC documents valid?
6. IPC concludes that the project has no effect on beach erosion since the material trapped in the upstream end of Brownlee Reservoir is not from the same parent geology as that found in the beaches in the HCW&S River. This was based on a limited number of samples and did not include any sampling in sediment plumes/deltas in tributaries to Hells Canyon Reservoir and Oxbow Reservoir which may be from the same parent material. Is the scope and scale of sediment sampling in Brownlee Reservoir adequate and should the other reservoirs be evaluated as well?
7. Is the "slug of sediment" theory valid since there was no data to support it?
8. In their information presentations, IPC has discounted the Grams and Schmitt studies on beach erosion and concluded that based on their own three consecutive years of trend data the beaches in HCW&S River are stable. Is this valid?
9. What (if any) additional studies or analysis are needed to address USFS concerns (primarily beach erosion)?

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Document #2

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United States Department of the Interior

U.S. GEOLOGICAL SURVEY

3215 Marine Street
Boulder, CO 80303

November 15, 2002

TO: Craig N Kendall
Forest Hydrologist
Wallowa-Whitman National Forest
U.S. Sorest Service

RE: Review of Idaho Power Company technical reports as they relate to sand beaches in the Hells Canyon Reach of the Snake River

FROM: **Kirk R. Vincent and Edmund D. Andrews**
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Dear Craig:

The following is in response to your request.

The Issues

Idaho Power Company (IPC) owns and operates three hydroelectric dams (Brownlee, Oxbow, and Hells Canyon Dams) on the Snake River along the Idaho-Oregon border. These three dams and their reservoirs are collectively known as the Hells Canyon Complex (HCC), and operate under a single license granted by the Federal Energy Regulatory Commission. Idaho Power Company is currently in the process of renewing the license for these facilities. The HCC is located in a deep canyon downstream of the confluence of alluvial rivers including the Boise and Payette Rivers and well upstream of the Salmon River. The HCC is located immediately upstream of the reach of the Snake River in "Hells Canyon", which bisects the Hells Canyon National Recreation Area (HCNRA).

Our Assignment

We were asked by the US Forest Service to evaluate the technical conclusions drawn by the Idaho Power Company that the three dams on the Snake River comprising the Hells Canyon Complex have not had a detrimental effect on sand beaches in Hells Canyon. Sand beaches are an important recreational resource for the 500,000 people who visit the HCNRA each year.

We offer the following evaluation of the issues based upon the technical information presented by IPC, information in scientific publications, and our professional experience. We reviewed technical reports issued by Idaho Power Company in 2002 including report E1-1, report E1-2, and Special Appendices A-B to report E1-1. These are evidently draft reports and we reviewed versions as they existed in March of 2002. The exact length and position of what is, or should be, called Hells Canyon is debatable (Vallier, 1998). When referring to "Hells Canyon" or the "Hells Canyon Reach" we mean the free-flowing reach of the Snake River, and the landscape adjacent to it, from Hells Canyon Dam downstream to just above the Salmon River confluence. In our analysis of the technical issues we make calculations using the information provided by IPC, presuming the information provided is correct. In certain instances the information provided is unclear or incomplete. In those cases we evaluated the mathematical consequences of the necessary assumptions to make sure our results were conservative.

Overview of the IPC Logic

The Idaho Power Company concludes that the HCC has not had a substantial detrimental impact on Hells Canyon beaches. This conclusion is based largely on their argument that the watersheds adjacent to Hells Canyon supply far more sand to the river then is trapped in the HCC reservoirs just upstream. The IPC acknowledges that the sand trapped in the HCC reservoirs would otherwise be a source for maintenance of beaches in Hells Canyon, but that the local source of sand is far greater and thus is sufficient for maintenance of Hells Canyon sand beaches.

Although IPC acknowledges that sand beaches have diminished since dam closure, they suggest that this would have happened even if the HCC had not been built. The IPC hypothesizes that a "slug of sediment" caused by development upstream arrived in Hells Canyon before dam construction and coincidently exited Hells Canyon after dam construction.

Have Sand Beaches Diminished in Hells Canyon

The obvious place to start is to ask if beaches in Hells Canyon have diminished since construction of the HCC or not. For reference, Brownlee Dam was completed in 1958, Oxbow Dam in 1961, and Hells Canyon Dam in 1969. Grams and Schmidt have studied extensively the sand beaches in Hells Canyon and concluded that the number and aerial extent of beaches has decreased substantially since closure of the HCC (Grams, 1991; Grams and Schmidt, 1999a, 1999b). Only 27% of the beaches that existed in 1955 remain today. Most of the reduction occurred between 1964 and 1973 and essentially all of it between 1964 and 1982. Those are two of their several observations.

Idaho Power acknowledges that sand beaches in Hells Canyon have decreased in number and extent since dam closure. Reference is made to this in several places within their reports: "Decreases in sediment storage associated with the sand bar complexes have been documented over the past 40 years . . " (IPC, 2002, report E1-2, page 6-9). "Over the timeframe of decades, these features [sand bars and beaches] appear to be generally eroding and/or undergoing localized deposition and erosion." (IPC, 2002, report E1-2, page 6-6). "Changes in the river observed since the construction of the HCC (such as shrinking sand beaches) may be caused . . ." (IPC, 2002, report E1-1, page 2).

The results produced by Grams and Schmidt have been included in peer-reviewed professional publications (Schmidt et al., 1995; Collier et al.; 1996). We have reviewed the reports of Grams and Schmidt and find that their methods adhere to long established standards of the profession, and that their observations are conclusively demonstrated. Sand beaches in the Hells Canyon Reach decreased in number and aerial extent during the two decades following dam closure.

Idaho Power Company is aware of the work of Grams and Schmidt (e.g. IPC, 2002 report E1-2, page 5-30). Idaho Power does not object to the methods or results of Grams and Schmidt, only what caused the beaches to diminish. The IPC also conducted their own study of the beaches in Hells Canyon, but their studies considered only limited number of beaches, short reaches of the river, and encompass very restricted periods of time. The IPC did not consider the time period (1964 to 1982) when the change in the number and size of beaches occurred, and thus missed the issue of disappearing beaches altogether. The IPC suggests that changes in Hells Canyon beaches are within the range of natural year-to-year changes to be expected of beaches along rivers. They did not, however, present any supporting information considering the period of rapid change in beaches within Hells Canyon, nor any supporting information for similar rivers in the Pacific Northwest.

In conclusion, the available evidence indicates that the number and aerial extent of beaches in Hells Canyon has decreased substantially since closure of the HCC. There is no available evidence suggesting that the observed magnitude, the timing, or the rates of change of Hells Canyon beaches could occur on a river except just downstream of dams.

Why Have Beaches Diminished in Hells Canyon

Idaho Power acknowledges that there are relatively few sand beaches in Hells Canyon, and suggest that sediment trapping behind reservoirs upstream of the HCC are responsible. "Although sand bars should be present [in Hells Canyon] within the lees of debris fans where eddies create backwater currents, such sand bars are conspicuously absent or are relatively small in extent. The reasons for this are unclear, although the lack of upstream sediment that has been primarily cut off from the canyon by other regulation projects may be a contributing factor." (IPC, 2002, report E1-2, page 6-7). The IPC acknowledges that the sand trapped in the HCC reservoirs would otherwise be a source for maintenance of beaches in Hells Canyon.

In contrast, the diminishment of beaches in Hells Canyon has been described as a classic example of the direct consequence of sand depletion by dam impoundment (Collier et al., 1996). The simplest and most obvious explanation of cause and effect for Hells Canyon beaches. The IPC suggest alternative causes to explain the observed diminishment of beaches in Hells Canyon, which we could find no basis for in the geologic literature.

Sediment Supplied from Hells Canyon Watersheds

Idaho Power Company concludes that the amount of sediment trapped in the HCC and thus not available to maintain Hells Canyon beaches is inconsequential because the local supply of sediment to Hells Canyon is so large. For example, on page 5-14 of report E1-2 the IPC states the following: ". . . local tributaries [to Hells Canyon] produce a total sediment supply of 15.1

million tons/year. On a strictly volumetric basis this estimate is about 5 times higher than the annual supply of sediment that has been retained by Brownlee Reservoir (2.78 million tons) since 1958." The logic behind that conclusion hinges on the validity of Idaho Power's estimated sediment yield for watersheds directly feeding into the Hells Canyon reach.

The supply of sediment from the tributaries in question has not been measured, and thus must be estimated. There are a variety of ways to estimate sediment yield that have long been accepted by geomorphologists and hydrologists. Idaho Power Company used one method to estimate the sediment yield, a theoretical sediment transport equation, without any supporting or corroborating measurements. In the following several paragraphs, we consider and evaluate the reasonableness of the IPC estimated sediment yield from Hells Canyon tributary watersheds by applying 4 tests:

1) How does the estimated sediment yield compare to yields measured worldwide?
2) Is the estimated sediment yield consistent with what is understood about deep and narrow canyons in general, and with the geologic history of Hells Canyon in specific?
3) Is the estimated sediment yield consistent with the sediment that has accumulated in the Hells Canyon Complex reservoirs located just upstream?
4) How does the estimated sediment yield compare to the rate of sediment accumulation in Snake River Basin reservoirs in general?

Based on these 4 criteria, the IPC has greatly overestimated the sediment supplied by tributaries adjacent to Hells Canyon Reach.

Using information from IPC and developed in this section, a following section constructs an independent estimate of the sand supplied by tributaries to the Hells Canyon reach and the sand trapped in the HCC reservoirs just upstream. We conclude that the Hells Canyon Complex of reservoirs trap approximately 95% of the sand that would otherwise be available to maintain Hells Canyon beaches.

Idaho Power Company estimated that the average sediment yield from Hells Canyon tributaries is 28,100 tons per square mile per year, sustained over time periods of many decades. They conclude that the current climatological regime, and therefore presumably rates of erosion, has persisted for the past thousand years. This rate is equivalent to 43.9 tons per acre per year, which is a common expression of sediment yield.

Dunne and Leopold (1978, pages 520-522) compiled and summarized sediment yields measured for a broad range of landscapes and land uses. The only published measurements of sediment yield equal to or exceeding the calculated IPC result (43.9 tons per acre per year) are from urban constructions sites, frequently graded dirt roads, and some croplands with thick unconsolidated soils in humid areas. Such very large sediment yields are associated with recent disturbance by bulldozers or plows over the whole area of sediment yield, very small areas of yield (acres or less), and continual disturbance of the land surface. In contrast, "Hells Canyon is characterized by . . . erosion-resistant basalt and metamorphic bedrock"(IPC report E1-2, page 5-4). Land uses in the 548 square mile watershed are evidently limited to some grazing and timber harvesting. The sediment yields inferred by IPC for the Hells Canyon tributaries greatly exceed that reported for sites of similar substrate and land use. The IPC erosion rate rivals that of the most erosive sites in the world.

The geomorphology of canyons has been studied for 150 years. Beginning with the earliest observers, geologists have recognized that steep canyon walls and cliffs are composed of hard erosion-resistant rocks. Unlike croplands, steep rock hillslopes can eroded more slowly then less steep hillslopes (Wahrhaftig, 1965). The body of geological knowledge on canyons recognizes that they cannot form unless the rate of hillslope erosion, i.e. hillside retreat, is substantially less than the rate of river incision.

Idaho Power's estimated erosion rate is inconsistent with the geological formation of Hells Canyon. About two million years ago Hells Canyon did not exist, and a large lake (Lake Idaho) covered much of the western Snake River Plain. An arm of this lake extend up a mountainous embayment to the present site of Oxbow Dam, until a north flowing tributary of the Salmon River eroded head ward (south) into this "Oxbow arm" of the lake. The lake drained through this newly formed outlet and the waters of the upper Snake River Basin were thus "captured" by the Salmon River. This history was first recognized by Wheeler and Cook (1954) and is accepted by geologists (Vallier, 1998). The incision rate of the Snake River has been determined. Wheeler and Cook (1954) concluded that the spill point was at what is now the Oxbow on the Snake, and estimated that the elevation of the lake surface was about 3,300 feet at the time of spillage. The present elevation of the Snake River bed at the Oxbow near the mouth of Pine Creek is about 1,700 feet, thus the incision amount is 1,600 feet. The spill over is thought to have occurred 2 million years ago, or somewhat earlier (Vallier, 1998). Accordingly, the long-term incision of the Snake River is 0.24 mm/yr. Next, we compare this incision rate to Idaho Power's erosion rate for Hells Canyon watersheds.

Erosion rates are frequently expresses in terms of land surface lowering. Sediment porosity is removed, and to do that we assumed a rock density of 3 gm/cc. Idaho Power's estimated sediment yield (28,100 tons per square mile per year) is equivalent to 3.3 mm per year (13 inches per century) of lowering of the entire 548 square mile Hells Canyon landscape. This watershed-lowering rate (3.3 mm/yr) is 14 times faster than the rate of incision of the Snake River (0.24 mm/yr), and thus is inconsistent with geological understanding of the formation of canyons.

As will be discussed below, the measured rate of sediment accumulation in reservoirs in the region is approximately 0.15 acre-feet per square mile per year. Assuming reservoir sediments have a porosity of 40%, this is equivalent to landscape lowering of 0.04 mm/yr. This rate is an order of magnitude less than the incision rate of the Snake River, and thus conforms to geological understanding of the formation of canyons. This information suggests that Idaho Power's erosion rate for Hells Canyon tributary watersheds is two orders of magnitude too high.

The magnitude and consequences of a sediment yield as large as that estimated by IPC can be demonstrated by calculating the volume of sediment that would have accumulated in Oxbow and Hells Canyon Reservoirs since they were completed, if the contributing watersheds eroded at a rate of 28,100 tons per square mile per year. The analysis is summarized in the following table. The information on the reservoirs is from the Idaho Power reports. The areas of landscape draining into the reservoirs were taken from IPC report E1-2, Figure 1.1, and are thus approximate. The porosity of sediment in Brownlee reservoir ranges between 40% and 65% (based on bulk densities given in IPC report E1-1, appendices A-B, page 3-1). We have used a porosity of 40% in order to be conservative.

	Oxbow Reservoir	Hells Canyon Reservoir
Completion year	1961	1969

Period of sediment accumulation as of 2002, years	41	33
Reservoir storage capacity, in acre-feet	57,500	170,000
Area of watersheds draining to reservoirs, miles^2	200	470
Sediment mass in reservoirs assuming the Idaho Power erosion rate of 28,100 tons per square mile per year, in tons	230,420,000	435,830,000
Volume of sediment in reservoirs assuming sediment porosity of 40%, in acre-feet	94,400	197,000
Percent of reservoir full of sediment	164% full	116% full

The watersheds draining into Oxbow Reservoir and Hells Canyon Reservoir are in close proximity or adjacent to the watersheds draining into Hells Canyon. All of these watersheds have roughly similar topography and bedrock. Therefore, we believe that the erosion rates for the various watersheds should be similar (the same order of magnitude). Applying Idaho Power's erosion rate to the watersheds feeding Oxbow and Hells Canyon Reservoirs suggests that both reservoirs would have filled and overflowed with sediment. Oxbow Reservoir is less than 1% full of sediment, if we understand the information in report E1-1 (page 87) correctly. This information suggests that Idaho Power's erosion rate for Hells Canyon tributary watersheds is more than two orders of magnitude too high.

Accumulation Rates of Sediment in Reservoirs

Idaho Power went to considerable effort to calculate the sediment yield from tributaries to Hells Canyon. Idaho Power repeatedly states that their estimated yield is "conservative" meaning that the "yield is intentionally lower than the most likely yield" (IPC, 2002, report E1-1, page 88). Therefore, it is surprising that Idaho Power did not compare their estimate to actual sediment yields measured in the region and within the Hells Canyon Complex itself. We make that comparison here.

Measuring the accumulation of sediment in a reservoir over a known period of years is the most reliable approach to determining watershed sediment yields. Idaho Power presented sediment yield data based on sedimentation surveys for reservoirs in the region (report E1-2, figure 4.1 and page 4-2; after USBR 1999). See their figure 4.1 attached. There are a total of nine sediment yield values for six reservoirs. The sediment yield values are remarkable similar, with seven of the nine values being between 0.11 and 0.17 acre-feet per square mile per year. The remaining two values, both from the granitic Idaho Batholith, are 0.39 and 0.52 acre-feet per square mile per year. Idaho Power assumed a regional average sediment yield of 0.15 acre-feet per square mile per year for reservoirs in the Snake River Basin that have not been surveyed. Not included in their figure 4.1, is Idaho Power's sedimentation survey of Brownlee Reservoir that determined a sediment yield of 0.14 acre-feet per square mile per year (IPC report E1-2, page 4-3). Furthermore, IPC conducted a sedimentation survey of the upper 4.5 miles of Oxbow Reservoir that resulted in a sediment yield of 0.22 acre-feet per square mile per year (IPC report E1-1, page 87) from a portion of the watersheds draining into that reservoir. In conclusion, sediment yields based on the eleven available reservoir surveys, including two in the Hells Canyon Complex, indicate that regional sediment yields are remarkably uniform, typically between 0.1 and 0.2 acre-feet per square mile per year.

Source	Reservoir	Sediment Yield Acre-ft/mi2/year
Attributed by Idaho Power (fig 4.1) to U.S. Bureau of Reclamation, 1999	Arrowrock	0.11
	Arrowrock	0.15
	Black Canyon	0.17
	Black Canyon	0.15
	Bully Creek	0.15
	Cascade	0.52
	Mann Creek	0.13
	Mann Creek	0.39
	Unity	0.13
Idaho Power Company	Brownlee	0.14
	Oxbow	0.22
Estimated by Idaho Power	for Hells Canyon Reach	12.9

The sediment yield to Hells Canyon estimated by IPC to be "28,100 tons/square miles/year" is equivalent to "32.5 cubic yards/acre/year" (IPC, report E1-2, page 5-13). Using this mass-to-volume conversion, IPC's estimated sediment yield for Hells Canyon is 12.9 acre-feet per square mile per year, or 86 times the measured rate in similar, adjacent and nearby watersheds.

Measured sediment yields based on reservoir surveys are commonly used to estimate sediment yields from nearby un-damed watersheds, and the consistency of measured yields in the lower Snake River Basin illustrates the validity of the approach. Accordingly, we believe that Hells Canyon tributaries downstream of Hells Canyon Dam contribute sediment at a rate similar to that of watersheds upstream of that dam. To compute the magnitude of sediment contributed by Hells Canyon tributaries relative to the mainstem transport in the absence of the HCC, it is necessary to know the areas of sediment contribution upstream and downstream of Hells Canyon Dam. Currently the watershed area above the Salmon River confluence not blocked by a dam other than the HCC is approximately 13,600 mi^2 of which 538 mi^2 is between Hells Canyon Dam and the Salmon confluence (IPC report E1-2, page 2-17). Consequently, 96% of the watershed area above the (downstream) end of Hells Canyon that could provide sediment in the absence of the HCC is in fact upstream of Hells Canyon Dam. Assuming that sediment yields are uniform in the area, as the available evidence suggests, the Hells Canyon Complex blocks more than 96% of the sediment that otherwise would be available for maintaining beaches in Hells Canyon.

Because the area contributing sediment above Hells Canyon Dam is so much larger than the watersheds within the Hells Canyon Reach, any reasonable estimate of sediment yield below Hells Canyon Dam could not change this result substantially.

<u>Sand Budget</u>

It is sand that is needed to maintain riverine beaches, not gravel or clay, so the issue is not total sediment supply but the supply of sand. We ignore the silt contained in beach sediments because the information needed to include silt was not provided. Ignoring silt, mathematically, acts to support not detract from the logical argument that IPC presented. Idaho Power has, or should have, all of the information needed to construct a sand budget, and should do that. We have almost enough information and illustrate how.

Below we develop a sediment budget to compare the magnitude of sand supplied by tributaries adjacent to Hells Canyon to the magnitude of sand that would have been supplied if not for the HCC. Sediment budgets are essentially quantification of sediment inputs, changes in storage, and outputs. Sand passing the Snake River gage near Weiser is an input to the budget. The sand stored in Brownlee Reservoir allows calculation of the sand input from the watersheds between the Weiser gage and Brownlee Dam. Sand input from all watersheds adjacent to Oxbow and Hells Canyon Reservoirs is knowable using reservoir surveys, but has not been provided. Sand input from watersheds adjacent to the Hells Canyon Reach is not known. These unknown sand inputs are estimated using an assumption justified by the available reservoir sedimentation surveys. The volume of sand stored along the banks of the Snake River is small. Therefore the sum of these inputs should equal the output of sand from the Hells Canyon Reach, in the absence of the HCC.

Why Exclude Very-Fine Sand

The amount of sand (of all sizes) trapped in Brownlee Reservoir is crucial to making a sediment budget and that was surprisingly difficult to find in the IPC reports. Where IPC makes statements involving sand, it is not clear if they included very-fine sand or even fine sand in their calculations. Concerning the sizes of sediment in Brownlee Reservoir, IPC states that “less than 4% of the sediments consist of fine sand-sized and larger particles”(report E1-1, page 85), but elsewhere contradict themselves by stating that of the sediments in the reservoir “less than 4% are larger than fine sand” (report E1-1, page 72). Below, we calculate that 16% (not 4%) of the sediment mass in the reservoir is sand and gravel, using data from report E1-1 (page 4-22). This discrepancy may also be due in part to fact that IPC’s does not always clearly identify whether their statistics are based on sediment mass or on sediment volume.

In any case, riverine beaches are composed of sand of all sizes. Idaho Power (report E1-1, figures 14 through 17) reports that the Hells Canyon sand deposits that are clearly pre-dam in age contain as much as 30 to 50% fine and very fine sand. This is to be expected, based on the results for sand bars elsewhere. Of the 67 Grand Canyon sand bars sampled by Schmidt and Graf (1990) most (43) have mean grain size within the very-fine sand and fine sand ranges. Beaches along the Salmon and Clearwater Rivers in Idaho are similarly composed primarily of very-fine and fine sand (Ned Andrews, unpublished data).

Sand Passing the Weiser Gage

There is an important stream gage on the Snake River near the town of Weiser, Idaho, and downstream of the Weiser River confluence. Suspended sediment and discharge measurements made at that gage indicate average transport by the Snake River of “1.09 million tons/year of suspended sediment of which 79 percent was silt and clay” (IPC report E1-2, page 4-15; after USGS 1997a). Accordingly, 21% of the measured suspended sediment (0.23 million tons per year) is sand. Assuming, as does Idaho Power, that the Snake River between the gage and Brownlee Reservoir is not aggrading, all of the sand passing the Weiser gage is transported into Brownlee Reservoir. Thus, 0.23 million tons per year is a minimum estimate of sand supplied by the Snake River to Brownlee Reservoir and no longer transported into Hells Canyon because of the reservoir. This sand supply is a minimum because sand transported as bed-load past the Weiser gage has not been quantified. There is additional sediment supplied from the watershed surrounding the 16 miles between the Weiser gage and Brownlee Reservoir, but that can be estimated using the reservoir sedimentation data.

For reference, this minimum amount of sand passing the Weiser gage is equivalent to 26 tons/mi^2/year, and is similar to the 44 tons/mi^2/year maximum yield of sand between the Weiser gage and Brownlee Dam calculated below.

Sand in Brownlee Reservoir

Idaho power evaluated the volume, mass, and grain-size distribution of sediments trapped in Brownlee Reservoir. The details of the reservoir survey are elusive, so we cannot evaluate their methods or their results. Given the elongate nature of the reservoir and the 100-foot range in pool level, the locus of sediment deposition must be highly variable through time. There are also both large and small tributaries entering the reservoir. Consequently, the stratigraphy is highly complicated and sediment textures are highly variable spatially. We suspect that the limited number of sediment samples, and the locations of samples are insufficient to accurately characterize the overall texture of the reservoir sediments. For example, as described above, 21% of the suspended sediment mass passing the Weiser gage is sand, but only 16% of the sediment mass in the reservoir is reported to be sand plus some unknown amount of gravel. It appears that the sand supply is being diluted by silt and clay that enters between the Weiser gage and Brownlee Dam. Given the more rugged terrain downstream of the gage, we would expect proportionally smaller supply of silt and clay downstream of the gage, compared to that from upstream of the gage.

"The post-1958 sediment volume in Brownlee Reservoir is 62,046 acre-feet, as measured from the 1999 bathymetric survey" (IPC, report E1-2, page 4-3). They conclude that this equates to 2.78 million tons per year (report E1-2, page 4-22). Also on page 4-22, they list the sediment supply by size class: silt and clay (2.39 million tons/year), very fine sand (0.1 million tons/year), fine sand (0.17 million tons/year), and medium sands to gravels as (0.11 million tons/year). Taken at face value, the supply of sand plus some gravel to the reservoir is thus 0.38 million tons per year (16% of the total mass).

The Budget Calculation

Of the 0.38 million tons per year of sand reportedly supplied to Brownlee Reservoir, at least 0.23 million tons per year is derived from upstream of the Weiser gage and the remaining 0.15 million tons per year is presumably supplied by watersheds between the Weiser gage and Brownlee Dam. This estimate overlooks the sand passing the Weiser gage as bed-load, and our inability to exclude the gravel in the reservoir from the calculation. Both of these unknowns lead to overestimation of the sand supplied by tributaries and hill slopes. The watershed area between the Weiser gage and Brownlee Dam is not given, but one can estimate it. The watershed between Weiser and Hells Canyon Dam totals 4,100 square miles (IPC, E1-2, page 2-17), and this includes the area draining directly into Oxbow and Hells Canyon Reservoirs that we previously estimated to be somewhat less than 700 square miles. Therefore, we attribute 0.15 million tons per year of sand to an area of 3400 square miles, resulting in a rate of 0.000044 million tons of sand per square mile per year. Assuming this rate applies to the 700 square miles around Oxbow and Hells Canyon Reservoirs, we calculate an additional 0.03 million tons per year bringing the total supply of sand from above Hells Canyon Dam to 0.41 million tons per year. Again assuming uniform erosion rates, we calculate a sand yield from the 538 square miles surrounding Hells Canyon to be 0.02 million tons per year. In conclusion, the Hells Canyon Complex of reservoirs traps approximately 95% of the sand that would otherwise be available to maintain Hells Canyon beaches.

Sediment Sizes and Mineralogy

Idaho Power spent considerable effort studying the sizes and mineralogy/lithology of sediments above and below the HCC, but we found this generally irrelevant to the issues or inconclusive. Idaho Power concludes that the coarsest sediment (cobbles and boulders) found in Hells Canyon were derived from local sources. This is to be expected, but the same is not necessarily true for sand. We found the sand mineralogy study inconclusive. The sand grain-size study was informative in one way. If we correctly understand that “cut banks” are exposures of terrace sediments, then these are the only sands sampled in Hells Canyon that were assuredly deposited before dam closure. Although limited in number these samples may reflect the texture of sand bars deposited before the HCC, and they are finer grained then currently active beaches nearby. If this result were upheld by comprehensive sampling, particularly if the difference in texture between terraces and active beaches decreased downstream from Hells Canyon Dam, this would strongly implicate that trapping of the finest sands in the HCC is the cause.

The “Slug of Sediment” Theory

Idaho Power acknowledges that sand beaches in Hells Canyon have diminished since dam closure, and suggest that this would have happened even if the HCC had not been built. The IPC hypothesized that a “slug of sediment” caused by land use far upstream arrived in Hells Canyon before dam construction and coincidentally exited Hells Canyon after dam construction.

The “slug of sediment” theory requires three basic things, particularly considering the large size of the Snake River Basin above Hells Canyon. The volume of sediment must have been large, the timing must have been just right, and that sediment liberated by increased erosion was not stored between the sites of erosion and Hells Canyon. Idaho Power argues for local storage: “The significant change in gradient between the headwater areas and the lower reaches of the Snake River Plain suggests that the lower reaches act as a sediment trap” (report E1-2, page 4-10). Since Idaho Power negates one of the necessary factors, we move on to the volume and timing issues.

Large volumes of sediment require that rates of erosion accelerated by the various human activities must have been large, and for most activities that requires the tools afforded by the Industrial Revolution. This is a timing issue discussed below. Large volumes of sediment also require that the aerial extent of the activities must have large (requiring large populations) and that the duration of the activities must have been long (requiring early onset of the activities).

Idaho Power (report E1-2, see figure 2.2 attached) exaggerates the population densities in the watershed. The statistics below are from Highsmith (1973). Lewis and Clark did not set foot in Idaho until 1805, immigrants passing through Idaho on the Oregon Trail (essentially none stayed in Idaho) did not add up to substantial numbers, 1,475 persons, until 1844. In 1845 the people of European decent living in Oregon, essentially all west of the Cascade Mountains, numbered only 6,000 persons, and only a handful lived Idaho at that time. Mormon farmers did not establish their first permanent settlement in Idaho (in the southeast corner of the Snake River watershed) until 1860. In 1870 the population of Idaho was only 17,804 people, and many of those lived outside the Snake River watershed. The population density of Idaho did not exceed one person per square mile until 1890 and 4 persons per square mile until 1910.

In order for Idaho Power's theory to be plausible the "slug" of sediment must have been introduced into the system early. It must have been introduced before closure of dams upstream of HCC, otherwise it would have been trapped, and early enough to allow time for transport of the sediment through the river network into Hells Canyon before 1958.

Idaho Power Company places the onset of all erosive activities far too early (see Figure 2.2 of report E1-2). The notion that beaver trapping in the Snake River Basin was "intense" beginning in 1800 is incorrect, because the Hudson's Bay Company's regional headquarters and shipping port was not consolidated at Fort Vancouver (Washington) until 1825, and they did not build the Idaho centers of the fur trade at Fort Boise on the Snake River and Fort Hall near present Pocatello until 1834. The latter two forts were closed in1856 (Highsmith, 1973, p. 11). The notion that agriculture was moderately intense beginning in 1800 is incorrect, because the first permanent settler in Idaho of European decent did not establish his farm near Lapwai , which is outside the Snake River Basin, until 1840 (Highsmith, 1973, p. 8). The notion that grazing was moderately intense beginning in 1825 is incorrect, because the cattle business in Idaho did not begin until 1870, and that was "on a small scale" (Highsmith, 1973, p. 12). The notion that timber harvesting was moderately intense beginning in 1850, is also too early because that predates the widespread local uses of the lumber and the ability to export the lumber.

Mining did begin in the 1860's, but the timing and erosional consequence of mining purported by IPC is misleading for several reasons. Massive sediment yields caused by mining require mining on an industrial scale. For example, between 1870 and 1900 thousands of claims were worked in the Silverton Mining District of Colorado, though only a few were economically viable and became more than an exploration pit. Sediment yields did not become substantial until after 1900: after steam drills became available and after industrial scale ore-milling plants were built (Vincent and others, 1999). In addition, mining impacted only an extremely small fraction of the Snake River watershed, and sediment from point sources tends to become diffused by dilution and local temporary storage as the sediment moves downstream.

Logging could have contributed considerable sediment (despite the relatively small fraction of the Snake River watershed that is forested) because the Payette and Boise River watersheds are largely forested. Industrial scale logging using chainsaws and bulldozers and subsequent accelerated sediment yields, however, did not become widespread until after World War II and after construction of dams on those rivers that act as sediment traps.

Agriculture involves the largest aerial extent of the various erosive land use practices, but is not a particularly viable source for the "slug of sediment". In 1970 approximately 80% of the cropland in the Snake River watershed, and essentially all of the cropland within 75 miles of Weiser, was irrigated (Highsmith, 1973). Widespread irrigation requires reclamation reservoirs, which trap sediment. Thus, much of the sediment eroded from farmland is likely trapped behind dams upstream of the HCC and could not have contributed to a "slug of sediment" in Hells Canyon.

In conclusion, We do not find Idaho Power's "slug of sediment" theory to be plausible. No data was presented that directly supports the theory.

Daily Flow Variations

HCC dam operations result in daily fluctuations in river discharge called "ramping" and this results in the river surface rising and falling several feet each day. Thus the river falls and re-exposes a portion of beach faces hundreds of times a year, rather than a few times yearly as was the case prior to dam constructions. It is likely that this process has contributed to the loss of beaches in Hells Canyon, but Idaho Power did not address the issue. Existing photographic resources could be used to address this question.

Sets of aerial photographs of the river corridor were taken in March of 1973 on four days, and each day the river was held at a specific discharge (5,000; 7,700; 12,000; and 18,000 cubic feet per second). These 1:12,000-scale photographs were obtained by the Army Corps of Engineers (Jack Schmidt, personal communication, 2002), Study of these photographic resources would serve two purposes. An unavoidable limitation of any aerial photograph interpretation of river beaches is that the photographs for different years were inevitably taken when the river was flowing at different discharges. In one photo a low beach might be submerged and thus not visible. In the next photo it might not be submerged and thus visible without an actual change in the beach having taken place. The photos mentioned above would allow an inventory of beaches visible at various discharges to be made, for a time period over which no change could have taken place. This would allow quantification of one uncertainty of the repeat-photograph method. In addition, this analysis might identify whether or not low beaches have changed more than high beaches, and thus be relevant to the flow ramping issue.

Conclusions

The available evidence demonstrates that the number and aerial extent of sand beaches in Hells Canyon have decreased substantially since closure of the HCC. Idaho Power acknowledges this, and presents no reliable evidence to the contrary.

The Idaho Power Company concludes that the HCC has not had a substantial detrimental impact on Hells Canyon beaches. This conclusion is based largely on their argument that watersheds adjacent to Hells Canyon supply far more sand to the river then is trapped in the HCC reservoirs just upstream. The IPC acknowledges that the sand trapped in the HCC reservoirs would otherwise be a source for maintenance of beaches in Hells Canyon, but that the local supply of sand is far greater and thus is sufficient for maintenance of Hells Canyon sand beaches. The logic behind Idaho Power's conclusion hinges on an estimate of the sediment yield from tributary watersheds adjacent to the Hells Canyon Reach. No direct measurements of sediment yield from these watersheds exist. Idaho Power used only one method to make their sediment yield estimate, a sediment transport equation, and did not compare their estimate to independent evidence.

We evaluated the reliability of Idaho Power's sediment yield estimate using independent information. The IPC estimated yield rivals that from the most erosive sites in the world. The estimated yield implies that the entire 548 square mile landscape surrounding the Snake River in Hells Canyon is lowering at rates in excess of a foot per century. This is 14 times faster than the rate at which the Snake River incised forming Hells Canyon. Applying this estimated yield to similar nearby watersheds indicates that both Oxbow and Hells Canyon Reservoirs would have filled and overflowed with sediment since they were built. In fact, Oxbow Reservoir is not even 1% full of sediment. The IPC estimated yield is 86 times greater then yields typical of the region, based on reservoir surveys including surveys of Brownlee and Oxbow Reservoirs. Idaho Power Company's conclusion that local supply of sand is far greater then that trapped in the HCC, and thus is sufficient for maintenance of Hells Canyon sand beaches, is not credible.

Measured sediment yields, based on sediment trapped in the Snake River basin reservoirs, indicate that erosion rates are remarkably uniform through out the region, including the watersheds adjacent to the Hells Canyon Complex. Because sediment yields appear to be regionally consistent, the issue of the relative magnitudes of sand-supplies comes down to the sizes of various areas that contribute sediment. The area of sediment supply above Hells Canyon dam is 13,600 square miles, whereas the area draining directly into the Hells Canyon Reach is 538 square miles. Using information supplied by IPC we developed a budget of sand supplies. We calculated that the Hells Canyon Complex of reservoirs traps approximately 95% of the sand that would otherwise be available to maintain Hells Canyon beaches. Any reasonable estimate of local sand supply to Hells Canyon could not change that sand budget result substantially.

Idaho Power explains the observed diminishment of sand beaches using a conceptual argument. They suggest that this would have happened even if the HCC had not been built. The IPC hypothesized that a "slug of sediment" caused by land use far upstream arrived in Hells Canyon before dam construction and coincidentally exited Hells Canyon after dam construction. We do not find any basis in the geological literature for a "slug of sediment" of the magnitude suggested by IPC. No data was presented that directly supports the theory.

The operation of HCC dams result in daily fluctuations in river discharge called "ramping". It is likely that flow ramping has contributed to the loss of beaches in Hells Canyon, and may continue to have detrimental effects, but Idaho Power did not address the issue. Existing photographic resources could be used to address this question.

No reliable evidence has been presented suggesting anything other than the obvious cause and effect: Hells Canyon beaches have diminished in number and aerial extent because the sand supply was dramatically reduced due to sand retention in the Hells Canyon Complex of reservoirs.

Sincerely,

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Document #3

Review of Idaho Power Company Documents Concerning Sediment-Related Impacts of the Hells Canyon Complex Dams on the Snake River in Hells Canyon

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1.0 Background and Structure of the Review

This report reviews documents prepared by the Idaho Power Company (IPC) in support of the application of IDACORP, Inc. for relicensing the T. E. Roach hydroelectric project, informally known as the Hells Canyon Complex (HCC). This project includes three dams located on the Snake River – Brownlee, Oxbow, and Hells Canyon -- that were completed between 1958 and 1967.

The application and supporting documents are approximately 25,000 pages in length, and a single paper copy of the application is reported to be contained in 33, three-inch thick binders (IDACORP, Inc. news release). Our charge was provided by Craig Kendall, hydrologist, Wallowa-Whitman National Forest, who provided us nine 'sediment transport review questions" (Appendix A) concerning the impacts of the HCC on the Snake River downstream from the HCC, especially within the Hells Canyon National Recreation Area (HCNRA). The area of concern includes the remaining riverine parts of the Snake River in Hells Canyon; other parts of the Snake River in Hells Canyon (as defined by Vallier, 1998) are inundated by Hells Canyon Reservoir and are not the subject of this review, except as pertains to computation of a system-wide sediment budget. Kendall requested that we focus our efforts on reviewing Parkinson et al. (2002). In support of this work, we also reviewed other supporting documents prepared by IPC, especially Miller et al. (2002). These documents were obtained electronically from the internet site http://www.collaborativeteam.org/usermain.asp . We also have reviewed previously published reports concerning the relationship between the HCC and downstream geomorphic resources (Grams, 1991; Schmidt et al., 1995; Collier et al.; 1996; Grams and Schmidt, 1999a, b).

In places, Parkinson et al. (2002) present lists of specific conclusions. Although our review addresses all these conclusions, we also provide point-by-point responses to some of these conclusions in Appendix B.

In our review, we examine key sediment-related resources. We define the essential sediment questions, the data collected and analyzed by IPC, and the conclusions that they reach concerning each topic. We comment on the merit of these conclusions and, where necessary, offer alternative interpretations of relevant data. We also describe future studies that can help resolve important uncertainties.

2.0 Introduction

Despite the length and complex detail of the IPC sediment and geomorphology studies, the basic issues are clear. The Snake River in Hells Canyon is a steep, high-energy river confined in a narrow gorge (Vallier, 1998; Miller et al., 2002). Sediment resources of primary interest are sand bars used as recreational campsites, fine-grained terraces that contain archaeological resources, and gravels of suitable size and location for spawning. The river has a large transport capacity relative to the rate at which sand and gravel are delivered to it. As a result, only a portion of the fine sediment delivered to the canyon is deposited and these deposits occur in locations, such as eddies behind debris fans at tributary mouths, that provide some protection from the flow. Studies in Grand Canyon, a canyon river system similar to Hells Canyon, show that the size and texture of eddy bars and channel-margin deposits are closely coupled to the sediment flux in the river (Rubin et al., 1998). These studies also show that the locations of these deposits are persistent but the sediments that comprise these deposits are transient and dynamic: their grain size and volume reflect the current water and sediment regime of the river. The deposits are maintained by a supply of sediment from upstream and, in the absence of such a supply, will be progressively eroded.

The three reservoirs comprising the HCC were completed between 1958 and 1967. The HCC produces a modest change in high flows within the Canyon and eliminates essentially all supply of sediment from the upstream Snake River watershed. The essential question is whether this mix—modest modification in high flows and elimination of upstream sediment supply—has produced a significant impact on sediment deposits in Hells Canyon. To address this question, two general issues must be addressed. First, what is the sediment supply to Hells Canyon and how has it changed following completion of the HCC? Central to this topic is the relative magnitude of upstream sediment supply (now eliminated by the HCC) and sediment supply from local tributaries below the HCC. Second, how have the sediment resources in Hells Canyon changed since completion of the HCC? An important concern here is distinguishing between natural variability of these dynamic sedimentary features and progressive change.

Once the sediment supply and sediment dynamics issues have been addressed, the remaining task is to connect the two, looking for plausible cause and effect. This is not an easy job. There is uncertainty in estimating sediment supply. Sandbar, terrace, and spawning gravel deposits exhibit spatial and temporal variability in their volume and composition. In the face of this uncertainty, estimates of reduced sediment supply must be compared to estimates of sediment loss from Hells Canyon.

We organize our report around these central issues: sediment sources, sandbar dynamics and terrace erosion, and spawning gravel dynamics.

3.0 Sediment Sources to Hell Canyon

The report acknowledges that the HCC traps sediment delivered by the Snake River to the HCC. Evaluating the impact of the HCC on sediment resources in Hells Canyon depends directly on the amount of upstream sediment supply that has been lost relative to the amount that is still supplied by local tributaries downstream from the HCC.

3.1 Upstream Sediment Supply

Sedimentation History in the Upper Snake River Basin: the "Sediment Slug"

IPC argues that accelerated erosion in the Snake River watershed upstream from the HCC occurred in the late 19th and early 20th centuries and the resulting sediment was subsequently transported downstream. IPC asserts that this "slug" of sediment, the product of unusually high erosion rates in the upstream watershed,, would have produced large bars in Hells Canyon, thereby biasing any interpretation that the HCC might have had an impact on Hells Canyon sediment resources. According to IPC, observations of decreased sand bar size are related to post-slug adjustment to "normal" conditions and are unrelated to the HCC. We agree that 19th century agricultural, forestry, and mining practices probably introduced large quantities of sediment into the watershed's streams. The issues relevant to the HCC, however, concern whether or not sufficient sediment was delivered to Hells Canyon in amounts that would have created unusually large sand or gravel bars, when this sediment arrived in Hells Canyon, and how long such deposits might have persisted in Hells Canyon. We disagree with IPC's findings on all of these accounts.

Studies conducted elsewhere in the United States suggest that IPC's assertions are probably wrong, are misleading, and cannot be evaluated without additional data. The primary issue is not whether there were high sediment yields in the mined lands, forests, or farm fields of Idaho, but whether or not these sediments ever reached Hells Canyon. Processes similar to those suggested by IPC were described by Gilbert (1917) for the movement of hydraulic-mining debris from the Sierra Nevada foothills into the Central Valley of California. Gilbert (1917) described the slow movement of a "wave" of mining debris that caused bed elevations of the Yuba and

Sacramento Rivers to raise 3 to 5 m approximately 10 to 20 years after cessation of large-scale mining in the watersheds, and to return to their former elevation during the next 30 to 40 years. Estimates of the volume of hydraulic mining debris generated in the Sierra foothills are extraordinary, unprecedented in the American West, and likely to have been much larger than those generated in central Idaho. Even in California, however, James (1989, 1991, 1993) showed that sediment yield in other mined watersheds remained high in the late 20th century, and did not resemble the wave described by Gilbert (1917) for the Yuba River. Sustained sediment delivery has occurred elsewhere, because so much mining debris remains in small order valleys and on hillslopes. Thus, a slug may have moved from central Idaho, or sustained high levels of transport might continue to this day, such as at Mann Creek Reservoir on the upper Weiser River and Cascade Reservoir (Miller et al., 2002, Fig. 4.1).

However, it is more likely that much smaller amounts of sediment have actually reached the Snake River from headwater basins, because there are abundant locations where the products of accelerated erosion might be stored. For example, researchers have described the fate of the products of accelerated erosion in the Piedmont and Coastal Plain of the eastern United States (Trimble, 1974; Phillips, 1991) and the American Midwest (Trimble, 1983, Beach, 1994). These studies show that large proportions of the products of accelerated hillslope erosion move slowly downstream because of temporary storage in small watersheds. Happ (1945) estimated that alluvial valleys in South Carolina are covered by about 1.2 m of upland sediment eroded in the late 1800s and early 1900s from hillslopes and farm fields. Rather than a slug of sediment producing large sand bars in Hells Canyon well into the 20th century, we find it more likely that 19th century sediment from upstream has been long sequestered in bars and floodplains, with smaller amounts moved through the Hells Canyon prior to completion of the HCC. Certainly the sequestration of sediment higher in the basin has been made much larger by the construction of reservoirs during the 20th century.

There are observations that can be made to estimate the fate of the products of accelerated erosion. These include stratigraphic evidence of sedimentation in upland watersheds, historical data describing changes in stream-bed elevation through the river system, stratigraphic evidence in alluvial deposits along the Snake River, and historical accounts of the evidence of accelerated sediment transport. IPC presents little, if any, such evidence and the claims made are often internally inconsistent. For example, IPC asserts elsewhere that the streams draining central Idaho typically have deposited a large proportion of their loads in the Snake River Plain before reaching the Snake River. This observation makes it less likely that large quantities of sediment were delivered to Hells Canyon in the past. None of the reservoir sedimentation data reported by Miller at al. (2002, Fig. 4.1) suggest that sedimentation rates in Idaho batholith reservoirs were exceptionally high in the early part of the 20th century, although the rates reported for Mann Creek Reservoir on the upper Weiser River and Cascade Reservoir on the upper Payette are more than twice other estimates.

The interpretation that a sediment slug may have produced enlarged sand bars in the Hells Canyon depends not only on the delivery of large amounts of sediment, but on the persistence of this sediment within Hells Canyon for a long period of time. Sediment delivered in the early 20th century would have to remain within Hells Canyon for many decades in order to produce the enlarged bars that IPC argues existed in the 1950s. Such persistence is highly unlikely. Mean residence times for sediment in a narrow, high energy, canyon environment are likely measured in years, not many decades. Thus, it is unlikely that sediment delivered to Hells

Canyon in the early 20th century (even more, in the 19th century) would remain in Hells Canyon in any significant amount by the 1950s.

We conclude that IPC's interpretation of the fate of any excess historical sediment is inconsistent with well-documented cases elsewhere and is unlikely. The amounts delivered to Hells Canyon, the timing of this sediment delivery, and the small residence time of sediment make its presence in the canyon in any substantial volume highly unlikely at the time that the HCC was constructed.

In addition to being unlikely, IPC's conclusions about a historical sediment slug are speculative and unsupported by necessary observation. No data are provided to evaluate their assertion, much less the argument that bars in Hells Canyon were unusually large at the time immediately prior to dam construction. The assertion that sand bar area in Hells Canyon has declined in response to reestablishment of pre-slug conditions and that reestablishment coincidentally occurred at the same time that the HCC was built is merely unsupported conjecture. Data are needed if one is to evaluate whether such a sediment slug ever existed, ever reached Hells Canyon, or ever passed downstream. The impact of the HCC on Hells Canyon sediment resources must be addressed by solid estimates of the sediment supply lost to the HCC, in comparison to the amount supplied by local tributaries below the HCC and the amount of sand lost by sand bars.

Quantifying the Magnitude of Sediment Yield from the Upper Snake River Basin

In an effort to demonstrate that the reduction in sediment supply to Hells Canyon is due to dams *other than* the HCC, Parkinson et al. (2002) estimate the amount of watershed area above the HCC that was blocked by dams before the HCC was constructed. The total drainage basin area upstream from the Snake River confluence with the Imnaha River is reported to be 74,238 mi^2, of which 60,200 mi^2 are upstream from dams constructed prior to construction of Brownlee Dam in 1958 (Miller et al., 2002). Of the remaining 13,638 mi^2 basin above Hells Canyon Dam, 96% was blocked by the HCC: 9000 mi^2 is upstream from Weiser, ID and 4,100 mi^2 drains into the Snake between Weiser, ID, and Hells Canyon Dam (data from Miller et al., 2002). Only 538 mi^2 drains directly to Hells Canyon downstream from the HCC.

The report assigns sediment yield values to the different parts of the Snake River Basin in order to estimate the amount of the total basin sediment yield that is trapped in Brownlee reservoir relative to other reservoirs upstream. IPC concludes that "Brownlee Reservoir has only trapped 8% of the total volume of sediment accumulated within the basin upstream from the HCC" (Miller et al., 2002, p. 4-23). We find this estimate to be a serious underestimate, due to a persistent bias in the calculations designed to overestimate the sedimentation in upstream reservoirs and thus minimize the proportional sedimentation in the HCC. As an illustration of this bias, the sediment yield value to reservoirs upstream from the Owyhee River is estimated to be 0.15 af/mi^2/yr (330 tons/mi^2/yr) for Swan Falls and American Falls Reservoirs. This estimate is inconsistent with Miller at al. (2002, p. 4-7)'s own estimate of 0.0018-0.028 af/mi^2/yr (3.9-61 tons/mi^2/yr) developed from USGS (1994, 1995) transport data for the same part of the watershed. Thus, IPC argues that there is high sediment yield, or low sediment yield, in this part of the basin, depending on how it suits their argument. In fact, the comparison on which Miller et al. (2002)'s 8% estimate is computed compares the total estimated reservoir sedimentation in the 20th century with sedimentation in Brownlee Reservoir since 1958. IPC repeats this 8% estimate throughout its summary documents in an effort to discount the role of the HCC in blocking sediment transport of the Snake River, and this estimate is a deception.

The total amount of sediment IPC (Miller et al. 2002) estimates to be stored in Brownlee Reservoir (1,550 acre-feet/year or 2.78 million tons/year) can reasonably be derived from the 9000 mi^2 upstream from Brownlee that were not blocked by reservoirs at the time of HCC construction. The sediment yield for this basin would be 0.172 af/mi^2/yr (373 tons/mi^2/yr), which is similar to the estimated average sedimentation rates for reservoirs draining western Idaho and eastern Oregon, as reported by Miller at al. (2002) (Table 1). Similar rates of sedimentation are reported by Miller et al. (2002) for deposition into Unity Reservoir on the Burnt River and into Oxbow Reservoir derived from the Wildhorse River.

IPC makes no comprehensive estimate of reservoir sedimentation into the entire HCC, making it difficult to evaluate the total sediment-trapping impact of the HCC on the downstream environment. The reservoir sedimentation data for Oxbow and Hells Canyon Reservoirs are poor to non-existent, and IPC reports that sediment yield increases downstream. Assuming the same yield as for the 9000 mi^2 basin upstream from Brownlee – 0.172 af/mi^2/yr (373 tons/mi^2/yr) -- one reasonably estimates that total storage in the HCC averages about 2250 af/yr (4.9 million tons/yr).

These sediment yield estimates are vastly different from those that Miller et al. (2002) report for tributaries draining directly into Hells Canyon (discussed below). The reported average sediment yield for the downstream tributaries is 28,100 tons/mi^2/yr, a value roughly 100 times greater than estimated for upstream sediment supply. In general, IPC asserts that little sediment was delivered to Hells Canyon from the 13,100 mi^2 basin previously unaffected by dams, no sediment was delivered from the 60,200 mi^2 basin affected by dams, and that virtually all of the sediment in Hells Canyon was, and is today, supplied by the 538 mi^2 basin directly tributary to the river downstream from Hells Canyon Dam. This argument is simply not credible.

We find that the upper basin sediment yield estimates provided by IPC are internally inconsistent, and that a more reasonable interpretation of these estimates indicates that the HCC has trapped a large volume of sediment in proportion to the flux that formerly entered Hells Canyon from upstream. Analysis of the data provided by IPC is greatly hindered by the fact that Miller et al. (2002) change the units in the reported data, and these changes make it very hard to evaluate consistency in the data. A simple table of all reported values would facilitate analysis by critical readers.

Uncertainty associated with estimates of basin sediment yield can easily serve to obscure a more fundamental point. Evaluation of the impact of the HCC on downstream sediment resources depends quite simply on the sediment supply interrupted by the HCC and its magnitude relative to remaining sediment supply below the HCC. The upstream supply of import is that delivered to Brownlee reservoir, the upstream of the 3 HCC reservoirs. There are two independent sources of information for making these estimates: sediment gaging records at the Snake River at Weiser gage and sedimentation measurements in Brownlee reservoir. Estimates of sediment yield from higher in the Snake River basin are not only enormously uncertain, but also less relevant to the problem at hand.

USGS Gage: Snake River at Weiser

Parkinson et al. (2002) discuss the fact that the USGS has collected suspended sediment samples at the Snake River at Weiser gage beginning in 1977, but do not make much use of these data except to mention that 20% of the measured sediment load is sand-sized. These data can be used to provide an independent estimate of the Snake R. sediment supply to the HCC that can be compared to the estimate of Miller et al. (2002, table 4.5).

Between November 14, 1977, and September 10, 1999, the USGS measured suspended sediment concentrations 91 times. Of these samples, 60 have grain size information reported, and 53 of those samples report sand (coarser than 0.062 mm) in transport. The proportion of sand in the transport averages 19% and shows no significant trend with discharge (Figure 1). This proportion is similar to the estimates of the proportion of sand entering the Snake from the Boise and Payette Rivers, as reported by Miller at al. (2002, p. 4-12).

The measured sediment discharge at Weiser can be regressed on the water discharge to provide a rating curve for estimating sediment supply to the HCC. The rating curves for total suspended sediment discharge (sand + silt + clay) and sand discharge are given in Figure 2 for the 60 samples with reported grain size information. The rating curve for sand is somewhat steeper than that for the total suspended sediment, a commonly observed phenomenon. The rating curves can be multiplied by the reported daily mean discharge at Weiser to provide an estimate of upstream sediment supply to the HCC. For the water years 1911-2000, the average annual suspended discharge is 949,000 tons, including 208,000 tons in the sand size range. For the post-dam era (water years 1959-2000), the average annual suspended discharge is 978,000 tons, including 214,000 tons in the sand size range. In each case, sand makes up 22% of the total annual suspended sediment discharge. This estimate is similar to that calculated by multiplying Miller et al.'s average daily load estimate by 365 (2002, Table 4.5), which yields an estimate of 1,100,000 tons.

There are two reasons why the annual sediment transport rate at the Weiser gage may underestimate the actual sediment delivery to Brownlee Reservoir. First, daily average values were used in calculating the sediment load, which will underestimate the sediment discharge when discharge varies over the day. For a river the size of the Snake, these within-day variations are probably small, however. Second, we are interested in the transport of the coarser sediment, which will tend to be found in higher concentrations closer to the river bed. This material can be undersampled and, therefore, underrepresented in the sediment rating curve and calculation of sediment yield.

River cross-section stability

Parkinson et al. (2002, figure 69) report channel cross sections for the Snake River gage at Weiser. They conclude that the cross-section history indicates that the Snake River is not an active, mobile river. Inspection of Figure 69 reveals deposition of a bar 2 to 4 ft thick and more than 400 ft across during some periods of measurement. It is hard to reconcile bar migration of this magnitude with an inactive channel. Further, the report mistakenly associates stability in cross section with small transport rates. Consider a large concrete pipe: its cross section remains perfectly stable, but it is capable of carrying sediment at small rates or enormous rates, depending on the rate at which water and sediment are supplied to it. A river section, particularly if its bed is composed of coarse sediments, can perform the same way. It is incorrect to associate a stable cross-section with minimal transport rates. The essential question concerns the estimated flux of fine sediment, including sand, entering Brownlee Reservoir from upstream and the estimated disruption of this flux caused by the HCC. These estimates are better made from measurements of the flux and not of the cross-section within which it occurs.

Reservoir sedimentation

IPC's estimate of upstream sand supply relies primarily on records of sedimentation in Brownlee Reservoir. Although reports of resurveys of the reservoirs are not explicitly discussed, we deduce from Appendix B of Technical Report E.1-1 (Brownlee Reservoir Aquatic Sediment Study – Physical and Mineralogical Analysis, by CH2MHill) and discussion in Parkinson et al.

(2002) that the only bathymetric information available are pre-construction topographic maps with a 20 ft contour interval and a reservoir survey in 1997. This information is insufficient to develop an estimate of upstream sediment supply or its average sizes with the resolution necessary to answer questions about the impact of the HCC on sediment resources in the Hells Canyon. It is also striking that no data are presented concerning the bathymetry of Oxbow or Hells Canyon Reservoirs. It is thus impossible to develop an overall number of the total sediment trapped in the HCC, although we provide an estimate, described above.

CH2MHill (Appendix B) conducted a sampling program of river and reservoir sediments between 1998 and 2000. Sampling consisted of 3 deep cores, 18 grab samples along the river and in the mouths of six tributaries, and shallow sediment cores collected approximately every 5 river miles through Brownlee Reservoir. Although these samples provide a useful picture of the materials being delivered to and trapped in the reservoir, we find that they do not provide an adequate sampling scheme to describe the supply of the coarser sediment (sand and gravel) that is of primary interest regarding sediment resources in the Hells Canyon. The depositional environment in the upper Brownlee reservoir is complex, particularly due to the 100 ft variation in pool level over time (corresponding to a more than 20 mile shift in the upstream extent of the pool). Deposits of sand and spawning gravels within the reservoir are likely to be localized and a reliable estimate of their volume would require identifying, mapping, measuring, and sampling all major sand and gravel deposits. A sample every 5 mi simply does not provide the resolution needed to determine, even roughly, the amount of sand and gravel trapped in the reservoir.

There is certainly clear evidence of sand deposition in the reservoir. For example, the shallow sample at RM315 consists of 63% sand. This sample is 1 of only 2 located within what appears to be the primary delta deposit, located in the vicinity of lower pool elevations. It is likely that sediment deposited at higher pool levels would be reworked and deposited in this vicinity.

We conclude that the IPC estimate of 4% sediments coarser than silt is likely a large underestimate of the sand and coarser sediment volume in the HCC. A more reasonable estimate is that 22% of the total sediment stored in Brownlee Reservoir is sand, based on measurements at Weiser.

3.2 Tributary sediment supply

Method

Sediment supply from tributaries downstream from the HCC was calculated for 17 tributaries accounting for 55% of the 538 mi^2 area. Transport rates were estimated with the Schoklitsch equation using as input samples of bed material, a surveyed cross section, and a surveyed channel slope. A sediment-rating curve (sediment transport rate as a function of discharge) was developed using the calculated transport rates and a flow resistance equation for steep mountain streams. Annual sediment yield was estimated using the calculated sediment rating curve and an estimated flow duration curve for each stream. The flow duration curve was developed from USGS regional curves for the 20%, 50%, and 80% exceedance flows. These three flows were then fitted by a “log curve” to determine discharges at 5% exceedance intervals.

Uncertainty

There is enormous uncertainty associated with these estimates of tributary sediment supply. The primary sources of uncertainty are:

(1) *Transport relation*. Calculations of sediment transport rates from a formula (any formula) might optimistically be claimed to be accurate within a factor of two or three. In cases with limited input (as is the case here), that uncertainty could easily be an order of magnitude. That

is, an actual transport rate of, for example, 100 g per meter per second could very well be calculated as a transport rate of 10 g per meter per second or 1000 g per meter per second.
(2) *20/50/80 exceedance curve*: the stated standard error for estimating the 20%, 50%, and 80% flow exceedance at each site is –46 to 85%.
(3) *5% increments on the flow exceedance curves*: the actual exceedance values used in the sediment yield calculations are based on a log fit to the 3 estimated points at 20%, 50%, and 80%. Because the transport relation is nonlinear, most calculated transport actually occurs at the highest flows (in this case those associated with 15%, 10%, and 5% exceedance), which are estimated by *extrapolating* from the fitted line. Flow duration curves tend to be strongly nonlinear at the largest flows (e.g. exceedances smaller than 10%) and are unlikely to be fitted adequately by any simple trend. As a result, most of the calculated transport rates are produced by flows that are estimated using an inaccurate extrapolation from three data points that are themselves an estimate with large uncertainty.

None of the elements of the tributary sediment supply estimate alone would necessarily produce unacceptable uncertainty for a very approximate analysis. The Schoklitsch formula is a recognized, if rarely used, transport formula. The USGS regional curves provide some basis for estimating flow magnitude in ungaged streams. Extending a 3-pt flow duration curve to a 20-pt flow duration curve with a “log curve” gives a coarse estimate of larger flows, although more accurate approaches can be found. It is in combination that the uncertainties associated with each element produce an estimated sediment supply with so much uncertainty as to have no practical use.

In 3 of the 17 tributaries (including Wolf Creek, one of the largest), IPC calculates zero sediment supply. They offer this result as evidence that their calculation approach is conservative. This logic is weak and could be just as easily be used to argue that their sediment yield estimates for other watersheds are unreasonably large in the face of zero transport calculated for other watersheds. In fact, the only conclusion that can be drawn from the enormous range in sediment supply estimates (0 to 160,000 tons/mi^2/yr) is that the uncertainty associated with the estimates is enormous.

Bias

The report claims that the transport estimates are conservative, based on choices made in developing the calculation procedure. Although the factors cited (e.g. no transport until 85% of the sizes are moving; use of daily mean flow estimates rather than instantaneous flows) do reduce the calculated transport rate, another factor is likely more important and suggests that the calculated sediment supply is actually far too large.

The primary source of an overestimating bias is the use of the calculated transport capacity to estimate actual sediment yield. This means that IPC assumes that the tributary streams would be able to transport sediment at the calculated rates at all flows. This is unlikely. In a large flood (which would account for most of the transported sediment) in these steep tributaries, it is likely that much of the readily transported sediment would be rapidly mobilized and evacuated, leading to a rapid decrease in transport rates, or *supply-limited* transport. The authors observed loose sediment available for transport in some of these stream channels and suggest that this indicates that transport would not be supply limited. This is insufficient evidence. A conclusion that the transport could occur at full capacity at all flows would require documentation of the availability of transportable sediment *in quantities approximating those estimated to be transported*. In Granite Creek (which is calculated to supply more than <u>half</u> of the total tributary sediment supply), this would be more than 5 million tons of sediment *each* *year* (or 160,000 tons/mi^2/yr). No evidence is given that such quantities of sediment are available for transport, and we find this number to be improbably large.

Parkinson at al. (2002) report that the watershed area draining directly to the Hells Canyon below the HCC is 548 mi^2. Their estimate of sediment supply from this area is 16.6 million tons per year. This value is more than 16 times the annual sediment load measured on the mainstem Snake R at Weiser. The magnitude of the IPC estimate of local tributary yield is implausible relative to the volume of transport in the mainstem.

As reported by Miller at al. (2002), the watershed area draining directly into the HCC is 4,100 mi^2. The average sediment supply calculated for tributaries below the HCC is 28,100 tons/mi^2/yr. This value is two to three orders of magnitude larger than most of the estimates reported for any place upstream from Hells Canyon (Table 1), and well over one order of magnitude larger than the largest of those estimates. Although the landscape typically includes areas of high and low sediment yield, it would be unusual that the sediment yields would be so large downstream from the HCC yet so much less upstream. If a sediment yield of 28,100 tons/mi^2/yr were applied to the 4100 mi^2 drainage directly entering the HCC, then sediment delivery to the HCC reservoirs would be 53,000 acre-feet *each year*, a value almost as large as the 62,000 acre-feet reported by IPC over a 40-year period. More remarkably, this rate of sediment supply would have *entirely filled* all available storage in all three HCC reservoirs by about 1990. The IPC estimate of local tributary sediment yield is simply implausible.

3.3 Mineralogical and grain size analyses of sediment sources

Samples of river sediment in Hells Canyon were compared with river samples above the HCC and with samples taken from local tributaries to Hells Canyon. The mineralogy and grain size of the samples were compared to evaluate whether sediment in Hells Canyon is derived primarily from local tributaries or from the Snake River above the HCC. IPC concludes that the Hells Canyon samples are different from those upstream, indicating that the sediment source is the tributaries below HCC. In both the mineralogical and grain size comparisons, we find there is little basis to support these conclusions in the data presented and that the assumptions and sampling underlying the comparisons would not, in any event, allow such a comparison to be made.

In order to determine whether the HCC has altered the sediment supply to Hells Canyon, it is necessary to demonstrate that the sediments sampled within Hells Canyon are of pre-dam origin. If upstream sediments could be shown to differ significantly from pre-dam deposits in Hells Canyon, a case could be made that the sediment source has always been local and, therefore, that the HCC has had little impact on the sediment supply. If, on the other hand, one is comparing upstream sediments to post-dam deposits in Hells Canyon, one is merely documenting that the sediments *currently found in Hells Canyon* are derived from local sources, which may not be surprising given that the samples were collected in a highly dynamic environment more than 40 years after the upper basin was isolated from Hells Canyon.

Therefore, it is incumbent on those following this logic, i.e. IPC, to unambiguously demonstrate that they have sampled pre-dam deposits in Hells Canyon. Almost no description is given of the procedure used to select sample locations in either the sediment transport report or in Appendix F of Miller et al. (2002), which presents the mineralogical analysis. However, given the description of the sampling methods (most samples in Hells Canyon appear to have been collected by shovel during low water conditions) and the grain size of the samples, it seems reasonable to infer that the samples were collected from channel-margin deposits and bars that are actively transported during high flows. River discharge in the Hells Canyon in the 1990s included the largest flows on record; we find it likely that the sediment sampled was mobile during these flows and earlier post-dam high flows. Certainly, no attempt is made to suggest that these samples are pre-dam, and we find it unlikely that they would be. Notwithstanding this essential methodological flaw, the data presented do not indicate a dominant local source, as the report concludes. We demonstrate this below.

Mineralogy

For the coarse material mineralogy (Figure 1, top panel of Appendix F of the Geomorphology Report), the data indicate that a lithological trend exists in which a simpler, two-part lithology upstream of the HCC becomes more varied below the HCC. Given the height and steep slope of the canyon, one would expect local lithologies to appear in the river bed sediments within the canyon. However, this observation does not lead unambiguously to the conclusion that upstream rocks are not present in the riverbed sediments. More striking is the mineralogical information for the fine (< 4 mm) sediments. The mineralogy of both upstream and downstream samples is classified as almost entirely quartz/plagioclase and mafics. The upstream and downstream samples are largely indistinguishable, with the exception of the appearance of small amounts of metamorphic rock (1-10%) in the Hells Canyon samples. The mineralogical report (Appendix F) concludes that "the relative lack of K-feldspar in the downstream samples strongly suggests that finer bed sediments are derived from local sources, rather than bedrock sources up-river of the complex". Based on the lower panel of Figure 1 of Appendix F, this conclusion appears entirely unwarranted: the upstream samples also have no K-feldspar. The upstream and downstream samples are largely indistinguishable and, if anything, suggest a consistent sediment source rather than the local source claimed by IPC. Even if the Hells Canyon samples were demonstrably pre-dam and, therefore, suitable for an appropriate comparison, the data presented simply do not indicate a difference between upstream and downstream samples.

Grain size

Figures 72 and 73 of Parkinson et al. (2002) compare grain-size distributions for samples above the HCC, within Hells Canyon, and in local Hells Canyon tributaries. The report concludes, "the results … corroborate the conclusion that sediments in the Snake River below the HCC are from local sources". We find no basis for this conclusion. First, the spread in the data, and the overlap among the different curves, cannot be used to draw any clear conclusions. Second (and more significant), it is well known that the local hydraulic environment exerts a stronger control on the composition of deposited sediment than does the overall supply to a river reach. This is why studies looking for longitudinal variations in sediment grain size must rigorously sample from comparable local environments along the entire river (e.g. all samples collected from riffles, or from the upstream side of bars, etc.). No such local control on sample location is reported. In fact, it is safe to conclude that the local hydraulic environment of the Hells Canyon tributaries is certainly different from depositional environments along the mainstem. Even if the reported size distributions were truly different, the absence of sample location control makes any comparison based on grain size meaningless.

3.4 Summary on Sediment Supply

IPC asserts that there was an anthropogenically-derived "slug" of sediment that moved from central and southern Idaho into Hells Canyon during the first half of the 20th Century that was derived from accelerated hillslope and valley erosion caused by mining, agriculture, urbanization, grazing, and post-wildfire erosion (Miller et al., 2002, Chapter 2). This sediment entered Hells Canyon before the HCC was completed and observations of decreases in sand bar size are related to the natural reestablishment of smaller bars due to the evacuation of this "slug. We agree that historical erosion and sedimentation in the upstream watershed may have been large in the 19th and early 20th century. Our interpretation of the fate of any increased erosion is quite different from IPC's, however. Much of this sediment was probably deposited close to its source, much higher in the watershed. No evidence is provided that a substantial amount of fine sediment actually ever reached Hells Canyon. More importantly, no evidence is provided to demonstrate that sand bar size in Hells Canyon was unusually large in the mid 20th century and was related to arrival of this slug that may never have reached Hells Canyon. Any increased sediment load that reached Hells Canyon would have passed through the steep, high energy canyon quickly. The amount of sand that can be stored in Hells Canyon is limited, determined by the location and size of protected areas capable of storing sand. Studies in other debris fan-dominated canyons with abundant eddy deposits, e.g. Grand Canyon, show that bar size is sensitively adjusted to the sediment flux and bars decrease in size if the sediment flux greatly decreases. If a slug ever did reach Hells Canyon, eddy bars would have begun to diminish in size soon after the slug had moved downstream, and thus shrinkage of bars would have begun prior to construction of the HCC.

The IPC has not *demonstrated* their sediment slug hypothesis in any way, whether regarding evidence of increased sediment loads in the basin's rivers or evidence of larger sand bars in Hells Canyon. We find their interpretation implausible and inconsistent with documented cases elsewhere; it is clearly undemonstrated.

IPC makes a detailed effort to demonstrate that much of the sediment supply from the upper Snake River Basin was isolated from the Hells Canyon before the HCC was ever constructed. We find that their values of sediment yield are inconsistent with reasonable values found in the literature.Further, IPC takes both sides of the argument: that sediment supplies to Hells Canyon were sufficiently large to produce enlarged sand bars in Hells Canyon all the way up to the time of construction of the HCC and, at the same time, that sediment supplies to the Hells Canyon were sufficiently reduced by the time that the HCC was constructed that the HCC itself had little effect on an already much diminished sediment supply. In the end, this duplicity must be bypassed by solid information on the sediment supply to Hells Canyon.

Evaluation of the impact of the HCC on downstream sediment resources depends on the sediment supply interrupted by the HCC and its magnitude relative to remaining sediment supply below the HCC. The relevant upstream supply is that delivered to Brownlee Reservoir, the upstream of the 3 HCC reservoirs, as well as to Oxbow and Hells Canyon Reservoirs. There are two independent sources of information for making these estimates: sediment gaging records at the Snake River at Weiser gage and sedimentation measurements in Brownlee Reservoir.

A preliminary estimate of the upstream sand supply can be based on the Snake River at Weiser gage. The upstream supply of sand (>0.062 mm) for the Snake River at Weiser is about 215,000 tons per year, based on the 1959-2000 discharge record and the sand rating curve at the gage. This is likely an underestimate, because coarser sizes in transport travel close to the river bed and are proportionally missed by the sampling device.

The reservoir information presented by IPC is insufficient to develop a reliable estimate of sand supply at a resolution useful for identifying HCC impacts on downstream sediment resources. Parkinson et al. (2002) state that total sedimentation between pre-dam conditions and 1997 is 62,000 acre-feet and that 4% of this material is sand. Using an approximate bulk density of 100 lbs/ft^3, this represents approximately 135,000 tons per year of sand deposition over the

40-year time span. This value is 37% smaller than the value of 215,000 tons per year based on measurements at the Weiser gage. Using a more reliable estimate of the composition of sediment delivered to Brownlee of 22% sand (as indicated by the Weiser gage), the sand deposition in Brownlee Reservoir would be 745,000 tons per year, a value more than three times the Weiser sediment load estimate.

Because the sediment supply estimated for the Wesier gage is likely too small due to the missing sediment load near the bed and because the actual volume of sediment stored in Brownlee Reservoir is poorly known, we suspect that the annual sand supply sequestered by the HCC is likely to fall in the range 250,000 to 750,000 tons per year. This estimate is for sediment supply from the Snake River to Brownlee Reservoir and does not include the additional sediment supply from the 4,100 mi^2 watershed draining directly into the HCC.

If a reliable estimate of upstream sand supply is needed, the best course of action would be to comprehensively map, survey and sample sand deposits in Brownlee Reservoir. A less accurate alternative would be to add bed load sampling to the suspended sediment sampling at the Weiser USGS gage and increase the frequency of both samples.

The method used to estimate sediment supply from tributaries below the HCC has such enormous uncertainty as to render the calculations useless for any practical purpose. This uncertainty notwithstanding, a key assumption in the calculation (sediment supply calculated as full transport capacity) makes it likely that the calculated sediment supply is significantly overestimated.

IPC reports on core samples collected in Brownlee Reservoir showing that the size of sediment in the Brownlee delta are finer than the sizes of existing sands in Hells Canyon sand bars. Thus, IPC argues that sediments trapped in the HCC have no relevance to the sand bar resources of Hells Canyon. IPC's comparison of Hells Canyon sediment samples with samples above the HCC has no useful meaning for the arguments they make. Such a comparison could only be useful if the Hells Canyon samples were demonstrably pre-dam. They do not make this demonstration and, we suspect, the Hells Canyon samples used by IPC are composed of post-dam sediments. Thus, it is no surprise that these sediments would differ from upstream sediments. Even without this fundamental flaw in their logic, IPC tries to make a case when even cursory inspection of the mineralogy and grain size of the samples reveals no significant difference between samples within Hells Canyon and those from upstream.

The IPC License application states:

> Grams and Schmidt did not consider that 87% of the watershed upstream of the HCC was already behind dams (or sediment traps) by the time that Brownlee Dam was completed. Therefore, the majority of their assumed sediment supply was already unavailable. They also lacked information on sediments actually trapped in Brownlee Reservoir. Such information would have shown that only minor amounts of sand have been trapped. These sands are of the fine and very fine sizes and include almost no coarser sand sizes. In contrast, sandbars downstream have the full range of sand sizes, from very fine to very coarse sizes. Therefore, the applicant's analysis and findings invalidate several of the key assumptions on which Grams and Schmidt relied when they concluded that the HCC was the sole cause of sandbar degradation in Hells Canyon.

This statement is unfortunately misleading. The essential conclusions of Grams and Schmidt were that sand bars in Hells Canyon decreased in number and area following construction of the

HCC. This is a simple, empirical observation that depends on no assumptions about sediment supply to the Hells Canyon. Parkinson et al. (2002) ignore this obviously problematic finding, although Miller et al. (2002) acknowledge it. Neither report presents any evidence disputing the findings of Grams (1991) or Grams and Schmidt (1999). The proportion of the watershed above HCC that was already behind dams at the closure of Brownlee Reservoir is, essentially, beside the point. Judgments about whether the amount of sediment trapped in Brownlee Reservoir is “minor” requires a context: the interrupted sediment supply must be compared with the remaining supply below the dams and the amount lost from Hells Canyon. Although an estimate of sediment delivery to HCC can be made, there is no reliable estimate of the magnitude of sediment delivery from tributaries below HCC. It can be shown (discussed below) that the quantity of sediment trapped by the HCC is a large multiple of the amount of sediment eroded from Hells Canyon sand bars, indicating that sediment trapping by the HCC remains the likely explanation for Hells Canyon sand bar loss over the past half century. Finally, IPC’s use of today’s sand bar composition to estimate the eliminated sand supply involves a simple logical fallacy: today’s sand bars may not (and probably do not) have the composition of pre-dam sand bars.

4.0 Sand Bar Dynamics

The relationship between the studies of Miller et al. (2002) and Parkinson et al. (2002) is not explicitly discussed by IPC, and this limits critical analysis of the integrated view held by IPC regarding the fate of sand bars in Hells Canyon. In their identification of issues and concerns, Parkinson et al. (2002) recognize the importance of sand bars as a resource to river recreationists and note that there is widespread perception that the sand bars have eroded as a consequence of the operations of the HCC (E.1-1, p. 13). Their treatment of the subject is terse and includes no discussion of the relevant literature, although they describe quantitative measurements for limited time periods and for limited reaches of the Snake River. They also describe measurements of sand bar change in the late 1990s. Miller at al. (2001) discuss the previous studies of Grams (1991) and Grams and Schmidt (1999a, b) as well as referring to the results of Parkinson et al. (2002). Thus, we assume that the report of Miller et al. (2002) reflects the integrated opinions of IPC on this subject. Below, we evaluate the quantitative studies described by Parkinson et al. (2002) and the analysis of Miller at al. (2002).

4.1 Parkinson et al. (2002)’s Analysis of Sand Bars from Aerial Photographs

Parkinson et al. (2002) conducted a study of sand bars using historical aerial photographs. They used three methods: (1) repeat measurements of bar area from rectified aerial photographs, (2) measurements of bar position relative to stable reference points, also from rectified aerial photographs, and (3) a count of sand bar occurrence from aerial photographs. Because they do not present any results from the second method, only methods one and three are discussed below.

For the repeat measurements of bar area they selected 10 sand bars and measured the area of those bars in photographs from 1946, 1948, 1949, 1955, 1961, 1964, and 1968, although they did not measure every bar in each of those years. In their analysis, they measured area of exposed sand on digitized and rectified aerial photographs. Table 1 lists their 10 sites, which we have cross-referenced to the sand bars included in the study conducted by Grams (1991). Four of these are sites where Grams (1991) showed small or no significant change between 1964 and 1990, three are sites where Grams (1991) showed more than 50% of the bar eroded, and one is a bar that eroded completely. Two of the sites could not be reliably cross-referenced. Because

Grams (1991) showed that the number of bars decreased by about 75% between 1955 and 1990, the sites chosen by IPC are biased towards sand bars that have changed the least. Pine Bar, Salt Creek Bar, Fish Trap Bar, and China Bar are among the largest and most stable bars in Hells Canyon. While these may be appropriate monitoring sites, they are not representative of the overall condition of sand bars in Hells Canyon.

In their analysis of bar area, IPC adjusted the measured areas to account for discharge differences between photographs. However, they do not report what the discharges were for each of the photographs or give the exact date of the photographs. They adjusted bar area by assuming a sand bar slope and then calculating the horizontal position of the edge of water given a vertical change in water surface elevation. They assume the slope is the submerged angle of repose of sand, which is 28 degrees. They cite no other application of this assumption and provide no evidence to support the assumption. Because the sand is deposited in moving water and is almost continually affected by either stream flow or wind, there is no basis for assuming that the bars are at the angle of repose. A brief examination of the field data IPC collected at Salt Creek Bar, Fish Trap Bar, and China Bar shows that the bars are not nearly that steep. According to those data (Figures 29, 30, 31, 32, 34, 35, and 36) bar slopes are typically between about 5 and 10 degrees, but may be higher or lower. This range and variability of bar slopes would likely preclude the application of any area adjustment that uniformly applied a constant correction to all bars. Finally, they do not report the unadjusted bar areas, so it is impossible to know how severely the discharge adjustment affects the results.

IPC inventoried sand bars using 1946 and 1955 aerial photographs along 12.5 river miles beginning more than 42 mi downstream from Hells Canyon Dam. IPC provides no reasoning or justification for their study reach selection. They conclude that in this reach, the number of sand bars was similar in 1946 and 1955, which argues against their conclusion that Hells Canyon sand bars at this time were shrinking due to the passage of a “sediment slug” from the upper Snake River basin.

4.2 Parkinson et al. (2002)’s Sand Bar and Terrace Particle Size.

IPC presents grain-size distribution data for the active portion of four sand bars and the high terraces adjacent to two of those bars. They do not calculate median particle sizes, but the graphs show it to range from about 0.2 to 0.6 mm. The size of the sand in the terrace is smaller at both locations where those samples were collected. The terrace sand is about 0.1 mm smaller at Fish Trap Bar and about 0.5 mm smaller at China Bar. Thus, IPC’s conclusion that “*the material in the adjacent cutbanks is from the same source as the material in the current sandbars*” is not supported by the data they present. Conversely, IPC’s limited data suggest that the material in terraces may be significantly smaller than the material comprising the active sand deposits. Thus the material comprising pre-dam deposits may have been significantly finer than the contemporary post-dam deposits. The coarse sand that comprises today’s sand bars in Hells Canyon is likely related to the absence of finer sediments. In Grand Canyon, sand bar texture is closely coupled to the grain sizes of the suspended flux. Thus, the coarsening of Hells Canyon deposits as one moves from terraces to bars is most likely a reflection of the trapping of very fine sand, silt, and clay in the HCC. Thus, while IPC’s statement that sand bars in Hells Canyon are coarser than the sediment trapped in Brownlee Reservoir (p. 79) may be correct, it is incorrect to interpret this to mean that trapping of sediment in upstream reservoirs has had no effect on sand bars in Hells Canyon.

4.3 Sand Bar Monitoring Data

IPC presents sand bar monitoring data for three sites also surveyed by Grams (1991) and Grams and Schmidt (1999b). The IPC data span the period from 1997 to 2000 while the Grams and Schmidt (1999) data span the period from 1990 to 1998. IPC also report data for one additional site surveyed by Grams and Schmidt only in 1998. IPC does not discuss the earlier data and does not attempt to compare their surveys with previous measurements. Grams and Schmidt (1999b) showed that there were areas of aggradation and degradation of sand at each of these sites but that net degradation occurred at each site and the area of cobble armor increased at each site. Both the IPC data and the Grams and Schmidt (1999b) are too limited to make general conclusions regarding large-scale trends in sand bar storage in Hells Canyon. A sample of three or four bars for 60 miles of river is not sufficient. It is only possible to conclude that there is significant reworking of the sand each year and for the three sites surveyed by Grams and Schmidt in 1990 and 1998, there appears to be a trend of gradual net degradation of the sand bar surfaces. The IPC report states that "the banks remained stable" between 1997 and 2000. The Grams and Schmidt (1999b) data, however, show that the cutbanks into the high terraces have eroded significantly between 1990 and 1998.

4.4 Summary on Sand Bar Dynamics

A clear record of the change in sand bar number and area can be developed from the results of Grams (1991), Grams and Schmidt (1999b), and Miller et al. (2002). Sand bar size varied about a relatively large average condition until the late 1960s. After that time, sand bars quickly declined in size and the rate of sand bar loss was more rapid near Hells Canyon Dam than further downstream. The rate of change in bar area is much less today than in the first decade after completion of the HCC. This is strong evidence, free of any assumptions, that sediment trapping in the HCC, is responsible for the sand bar loss. The results of Miller et al. (2002) and Parkinson et al. (2002) do not substantially challenge or modify this story. The remaining issue to provide quantitative evidence linking (or refuting) a cause-and-affect relation between HCC and sand bar loss in Hells Canyon. IPCs arguments here hinge on the sediment budget issues analyzed in Section 3 of this evaluation. We find little credible data to support IPC's contention that the sand bars were unusually large just prior to completion of the HCC and that the decrease in bar area is unrelated to the existence of the dams.

IPC's License application states:

> Another key assumption on which Grams and Schmidt's conclusions depend is that the Snake River and specifically the sandbars in the Hells Canyon reach were in a state of dynamic equilibrium from 1955 to 1964. They did not consider anthropogenic disturbances in the watershed above the HCC. However, these disturbances initially increased the sediment supply to the Snake River, after which over 500 dams with over 10 million acre-feet of storage were built. Therefore, assuming that the Hells Canyon reach was at a state of dynamic equilibrium following approximately 100 years of upstream activity and development is not appropriate, and making this assumption leads to the erroneous conclusion that the HCC is responsible for all changes to sandbars in the Hells Canyon reach."

We separate evaluation of IPC's arguments between analysis of their critique of the results of Grams and Schmidt's studies and critique of the possible reasons for the historical changes described by Grams and Schmidt.

We can not find any place in either Parkinson et al. (2002) or Miller et al. (2002) where the historical evidence of decrease in sand bar area or volume determined by Grams (1991) or Grams and Schmidt (1999b) is questioned. These earlier studies are adequately summarized by Miller et al. (2002, p. 5-30), and the results are not questioned. Grams (1991) and Grams and Schmidt (1999b) showed that the number and area of river edge sand bars along the Snake River decreased greatly soon after completion of the HCC, and the magnitude of these changes decreases downstream. Grams (1991) showed that sand bars decreased in area and number by approximately 75% between 1964 and 1990. Most of this decrease occurred between 1964 and 1973. Grams hypothesized that most of the erosion occurred during high dam releases in 1965, 1970, and 1971, although he did not have the temporal resolution in sand bar measurements needed to prove this assertion. It is possible that much of the erosion documented by Grams (1991) occurred after 1968 and was missed entirely by the IPC analysis.

Rather than reevaluate the full historical and spatial record developed by Grams (1991) and Grams and Schmidt (1999b), IPC conducted studies of limited spatial and temporal scope that yield ambiguous results largely unrelated to the findings of the previous studies. The conclusions reached by IPC in their license application are not supported by their own reports, and the IPC arguments are based on assumptions and assertions about the sources and quantities of sand in transport and not on the historical data measured by Grams (1991) and Grams and Schmidt (1999b).

5.0 Erosion of Terraces in Hells Canyon

IPC asserts that there is little erosion of terrace deposits in Hells Canyon and where erosion occurs, it is unrelated to HCC operations because the flood hydrology of the Snake River has not been changed by the HCC. Miller et al. (2002) summarize the findings of Grams and Schmdit (2002a) concerning erosion at Tin Shed, but they state that flows did not overtop the terraces and thus could not have eroded terrace cutbanks. Grams and Schmidt (1999a, b) demonstrated that terrace cutbanks have retreated in many locations in the late 1990s, and that cutbank erosion has been associated with high flows that reach the lower half of many cutbanks. Although no measurements were made during the high flows of the late 1990’s, Grams and Schmidt (1999b) argued that these high flows must have caused cutbank erosion because they were the only significant geomorphic force operative on these areas. IPC points out that recreational foot traffic and wind might cause such erosion.

We believe that IPC’s argument that HCC flows are unrelated to terrace erosion is unsupported. No data are provided to support this contention, and the other processes that might cause erosion are entirely speculative. High flows did reach the base of many cutbanks in 1997, as mapped and surveyed by Grams and Schmidt (1999b) and the most reasonable interpretation of the cause of these measured bank retreat are those high flows.

6.0 Gravel mobility, with emphasis on spawning gravels

Parkinson et al. (2002) estimated the mobility of the river bed in Hells Canyon using estimates of bed surface grain size and calculations of shear stress derived from stage and energy slope calculations from a hydraulic model. In addition to calculations along 566 cross sections above the Salmon River confluence, calculations were made at 17 spawning gravel sites.

Grain size information for the main channel sites was collected from “photo sieving” of underwater video taken at approximately 600 locations along the river bed. Because the video was not taken at each of the cross sections used to calculate bed mobility, judgment had to be used when selecting the grain size sample used in the calculations, introducing an important source of error. Sediment grain size at spawning gravel sites was collected using the same or similar photo analysis approach (Groves and Chandler, 2201).

Bed shear stress was calculated for the main channel sites using the so-called depth-slope product, wherein the section average shear stress is calculated as the product of the specific weight of water, the flow hydraulic radius, and the flow energy slope. This provides a measure of the total shear stress (force per area) acting on the cross section, but not the stress acting on particular locations within the section. Shear stress for the spawning gravel sites was calculated by substituting local flow depth over the spawning gravels for the hydraulic radius.

Incipient motion of the bed material was evaluated using a dimensionless shear stress of 0.047. Because the dimensionless shear stress is calculated using the bed surface size distribution, (rather than the subsurface), a value of 0.047 may be expected to indicate small to moderate transport rates because a surface-based dimensionless stress for incipient motion is likely to be in the vicinity of 0.03 to 0.035 (e.g. Parker, 1990; Wilcock et al., 1996).

Calculations of sediment incipient motion based on bed grain size observations and shear stress calculations are highly uncertain. Grain size will vary within the spawning gravel deposit and the flow field over the spawning gravels will not be a simple 1d field for which the depth/slope product is appropriate. A section averaged dimensionless shear stress of 0.047 may be expected to be associated with moderate, even intense transport, at some locations throughout the section or at locations within the spawning gravels.

6.1 Stability, mobility, and the health of spawning gravels.

The report uses the term bed stability to indicate the presence or absence of sediment transport. In the report, a “stable” bed indicates an “immobile” bed and the intent of the report appears to be to document the general immobility of the river bed and of the spawning gravels. We find this to be a curious approach, inasmuch as immobile gravels below dams can be considered to be less suitable for spawning than are gravels that are mobilized with some frequency. Period mobilization of spawning gravels is thought to help maintain a state of looseness that facilitates redd construction and is often a specific objective of reservoir releases intended to provide beneficial “flushing flows” (e.g. Reiser et al., 1989; Biosystems Analysis Inc, 1992; Kondolf and Wilcock, 1996). The conclusion drawn by IPC that the bed and the spawning gravels are generally “stable” is a conclusion that the bed is generally immobile, putting the spawning gravels in a condition colloquially referred to as “fossilized”. Fortunately, we think that the mobility of the spawning gravels is likely larger (at least locally) than indicated in the report, based on the use of a section-averaged shear stress (or flow depth over spawning gravels) and a relatively large threshold dimensionless shear stress of 0.047.

An interesting factor is the New Years 1997 flood. If spawning success within Hells Canyon (above Salmon River) improved following that flood, or the area of successful spawning increased, this would suggest that the resupply of gravel from local tributaries during that event may have played a role in improving spawning gravels.

6.2 Summary on Gravel Mobility

The methods used by IPC to evaluate bed mobility are approximate. The conclusion that the bed is generally immobile is correct for large stretches of river composed of very large cobbles and boulders. However, we suspect that smaller gravels suitable for spawning are likely mobile under post-dam conditions and further study is needed to confirm this mobility. Reliable conclusions concerning gravel mobility require direct field observations and cannot be based on hydraulic models and calculated values of dimensionless shear stress.

7.0 Sand supply compared to sand bar erosion

Although no reliable estimate of sediment supply from tributaries below HCC is currently available, an initial estimate of the upstream sand supply that has been eliminated by the HCC can be usefully compared to the volume of sand bar erosion within Hells Canyon. Based on the sediment supply estimated for the Wesier gage and the actual volume of sediment stored in Brownlee Reservoir, we estimate that the annual sand supply sequestered by the HCC is likely to fall in the range 250,000 to 750,000 tons per year. This estimate is for sediment supply from the Snake River to Brownlee Reservoir and does not include the additional sediment supply from the 4,100 mi^2 watershed draining directly into the HCC.

An estimate of sand lost to sandbars in Hells Canyon can be based on the measured decrease in sandbar area of 139,355 m^2 between 1964 and 1990 for the Hells Canyon Dam to Salmon River reach (Grams 1991, Grams and Schmidt 1999b). It is difficult to estimate the thickness of eroded sand in bars, although the average eroded thickness is unlikely to be less than 1 m or greater than 3 m. So, a minimum estimate of sand lost from sand bars is approximately 140,000 m^2 and a maximum estimate is 420,000 m^2 plus another 45,000 m^2 lost in eroded areas below the water level for the photographs analyzed. Using a bulk density of 1765 kg/ m^3, this range of estimated erosion represents approximately 10,500 to 35,000 tons per year of sand lost to the sand bars.

The rate of sand bar erosion represents at most one-seventh of the rate at which sand is supplied to Brownlee Reservoir and is likely a much smaller fraction of the sequestered upstream supply. The reduction in sand concentration in Hells Canyon due to the removal of upstream sand supply could easily be associated with sand bar erosion of this relative magnitude. In the absence of a reliable estimate of sand supply from local tributaries, a cause-effect relation between sand trapping in Brownlee reservoir and sand bar erosion in hells Canyon remains a likely scenario with important supporting evidence.

8.0 Conclusions

Following construction of the HCC, the sand bars in Hells Canyon began to erode. The number and area of sand bars decreased most rapidly in the decade immediately following dam closure and sediment loss was greatest near the dam and progressed downstream. The evidence for sand bar loss, which is quite clear and is described in the studies of Grams (1991) and Grams and Schmidt (1999a,b), is acknowledged by IPC (Miller et al., 2002, p. 5-23 to 5-24, 5-30), not challenged on technical merit, but is generally ignored in the voluminous IPC reports. We find the evidence for large scale sand bar erosion beginning at the time of completion of the HCC to be the appropriate starting point for the related investigation of the causes of this loss.

The coincidence of sand bar loss with the timing and location of the HCC indicates a strong causal relation. This connection was pointed out by Grams (1991) and Grams and Schmidt (1999 a,b) , although their study included no sediment budget that would quantitatively link HCC operations with the sand bar loss. Nevertheless, the explanation of the causes of the documented decreases in sand bar area are consistent with studies on other debris-fan dominated canyon rivers downstream from large dams. Sand is stored in sheltered areas along the channel margins in these canyons. These deposits are dynamic, and sand is exchanged with the river flow each time the bars are inundated. When sand concentration in the main flow is large, more sand enters depositional areas than is eroded from it and the sand bars grow in number, area, and volume. When concentrations in the main flow are small, more sand is eroded from the deposits than is deposited, and the sand bars diminish in size. Thus, the volume of sand in storage is sensitive to the concentration of sand in transport and, therefore, to the supply of sand to the river. When the upstream supply of sand is eliminated by trapping in reservoirs, sand concentrations in the river decrease and sand bar erosion exceeds deposition, leading to the loss of sand bars. It is this simple connection between eliminated sand supply, reduced sand transport, and eroded sand bars that is the most likely explanation of the clear empirical evidence of decreasing sand bar area in Hells Canyon.

Quantification of this relationship between the HCC and downstream sand bar loss requires precise and accurate development of a sediment budget for the grain sizes of relevance to the Hells Canyon system. IPC is to be congratulated in their recognition of the need to develop such a budget, but the budget that they indirectly develop is both incomplete and misleading.

A reasonable estimate of the eliminated upstream sediment supply can be made, based on measured reservoir sedimentation and river gaging, although more certainty in this regard would be useful. The estimates of the quantity and sizes of sediment trapped by the HCC are not consistent with the record of sediment flux of the Snake River at Weiser, and it is very likely that IPC's characterization of the sizes of sediment in Brownlee are in error due to a limited sampling program. IPC offers no estimate of the total sediment intercepted by Oxbow or Hells Canyon reservoirs, even though their estimates of local sediment yield from drainages tributary to those reservoirs would suggest that the amount of sediment stored there is large.

The sediment supplied to the Snake River below the HCC (the only remaining sediment supply to the Hells Canyon) remains entirely undemonstrated. The extensively documented estimates provided by IPC are developed using an inappropriate methodology based on naïve assumptions, leading to estimates that are demonstrably inaccurate in terms of both their magnitude and variability. Quantification of the impact of HCC on sediment loss in Hells Canyon requires a credible estimate of the sediment supply from local tributaries below Hells Canyon Dam.

In the absence of a reliable estimate of the sediment supplied from local tributaries, it is not possible to estimate the proportional reduction in sediment supply caused by the HCC. It is possible, however, to compare the volume of eliminated upstream sediment supply to the volume of sand loss from the Hells Canyon. IPC did not present such a comparison. We find that the rate of sand loss in Hells Canyon is no more than one tenth of the rate at which sand had been supplied from upstream, but is now eliminated by the HCC. This ratio indicates that the sand bars in Hells Canyon represent a small proportion of the previous sand transport through Hells Çanyon, an observation that is consistent with, and supports, the conclusion that the HCC is largely responsible for sediment losses in Hells Canyon. This conclusion rests not only on the available empirical evidence linking a reduction in upstream supply (in time, space and magnitude) with the observed sediment loss in Hells Canyon, but is also consistent with our understanding of sediment dynamics in canyon rivers.

Rather than address the evidence demonstrating a cause-and-effect connection between the HCC and sand loss in Hells Canyon, IPC chooses to introduce a variety of arguments with the goal of diverting attention from the main issues, or of undermining the dam impact conclusion without addressing the primary evidence. In the latter category is IPC's estimate of local tributary supply. The intent here was clearly to develop a case that sediment supply from below the HCC is so enormous that any interference in the mainstem sediment supply (including its complete elimination) would have negligible effect on sand resources in Hells Canyon. Even without considering the implausibility of this effort and the weaknesses in the methodology, the results produced by IPC, on their own, demonstrate in their variability and absurdly large values that the sediment supply estimates are of no practical value.

A similar effort to undermine the dam-impact story without addressing the primary evidence is the claim that comparisons of sediment samples from the Hells Canyon with sediment samples upstream of the HCC indicate that sediment in Hells Canyon has a local source that is unaffected by the HCC. The data presented simply do not demonstrate the difference suggested by IPC. More critically, the comparison is based on fundamental conceptual flaw: in order to demonstrate that the Hells Canyon samples indicate a local supply unaffected by the dam, it is necessary to compare samples capable of demonstrating this point. The argument IPC wishes to make is that sediment in Hells Canyon *has always* had a local source, such that construction of the HCC would have a negligible influence on sediment supply to the Hells Canyon. This requires that the Hells Canyon samples must be clearly of pre-dam origin. IPC made no attempt to make such a demonstration and, based on the location of sampling and the flood record of the past decade, it is most likely that the Hells Canyon samples are post-dam. The upstream/downstream comparison of samples is simply not valid.

The main diversionary argument made by IPC concerns the existence of the sediment "slug" from the upper Snake River Basin. IPC argues that the existence of such a slug must be considered when interpreting sand bar changes in Hells Canyon. The fate of sediment produced by accelerated erosion in the upper Snake River Basin in the 19th and early 20th centuries is largely unknown but, based on analogy with other cases with some documentation, it is likely that most of this sediment remains higher in the watershed. Sediment that worked its way into Hells Canyon would be transient, with a storage time in the high energy environment of the Canyon measured in a few years to a decade. IPC made no effort to demonstrate the existence of a sediment slug migrating through the Snake River Basin, although data are available with which the case could be made. The sediment slug concept promoted by IPC is, quite simply, undemonstrated and unlikely. More to the point, however, is that it is irrelevant. It is not necessary to construct a sediment budget for the entire Snake River Basin in order to evaluate the impact of the HCC on sediment resources in Hells Canyon. Rather, it is sufficient and much more relevant to directly connect the sand bar loss in Hells Canyon (which has been measured) with the reduction in upstream sediment supply due to reservoir sedimentation (which now has an approximate estimate) and the remaining sediment supply from tributaries below the HCC (which remains unkown).

<u>We found the overall approach taken by IPC to be most discouraging. The available evidence on sand bar loss in Hells Canyon has been entirely omitted from the Parkinson et al. report. Air photo analysis clearly shows the coincidence in space and time of sand bar loss with closure of the HCC complex. Although IPC purports to investigate this impact, they simply omitted from their analysis all air photographs taken after closure of the HCC. This is a curious approach if the goal is to honestly investigate the possible impacts of the HCC on the Hells Canyon sediment resources. The photographic analysis clearly demonstrates the sand bar loss following closure of the HCC. IPC does not directly challenge these results, but instead raises diversionary challenges to vaguely stated "assumptions" behind it. Rather than present an objective and open review based on the best available science, IPC uses arguments that divert attention away from the real issues, or that undermine compelling conclusions regarding the HCC without directly addressing the scientific evidence.</u>

<u>9.0 Recommendations for future studies</u>

Informed decisions regarding reoperation of the HCC and other possible mitigation strategies require solid information on the altered sediment supply to Hells Canyon. The voluminous information provided by IPC does not meet these vital information needs. The uncertainty inherent in any attempt to rehabilitate a degraded river system requires that actions taken to rehabilitate sand bars and spawning gravels in Hells Canyon must be evaluated within an adaptive management context. Hence, a monitoring program must begin immediately in order to establish baseline information on sand bars, terraces, and spawning gravels and to begin determining their response to flow and sediment supply.

Sediment Budget

A reliable understanding of the impact of the HCC on sediment supply and an acceptable plan for guiding reservoir operations to preserve the sediment resources in Hells Canyon requires an accurate understanding of sediment supply, storage, and discharge incorporated within the overall framework of a sediment mass balance. This work includes the following elements.

(1) Tributary sediment supply. At present, there is no reliable estimate of local tributary sediment supply. Both the magnitude and timing of tributary sediment supply are important. Reliable estimates of sediment supply require direct field observation; calculations based on transport formulas are not acceptable. An estimate of tributary sediment supply includes the following elements.

- (a) Historical rates of sediment supply measured in all available reservoirs, including tributary deltas in Oxbow and Hells Canyon reservoirs and smaller reservoirs higher in local tributaries. To develop an adequate sample size, all available ponds and reservoirs in the region with geology, slope, and aspect similar to Hells Canyon should be investigated. Field surveys should include the volume and grain size of deposited sediment and the trap efficiency of the reservoir.
- (b) The most important flaw in IPC’s estimate of tributary sediment supply was the use of the calculated transport capacity to determine sediment yield, which assumes that monumental amounts of sediment were available for transport. Determination of actual sediment yield requires field work to determine the volume of sediment available for transport. This involves geomorphic mapping of colluvial and alluvial deposits, surveys to determine sediment volume and grain size, and an assessment of the erosion potential of these deposits. The number and selection of tributaries mapped should provide a representative sample of drainage area, geology, and aspect of the tributaries draining directly into Cells Canyon.
- (c) There is evidence that sediment supplied from these watersheds is stored on a multi-year basis near the mouths of these tributaries. Field work is needed to evaluate the periodicity of sediment supply at the mouths of tributaries draining directly into Hells Canyon. Geomorphic mapping and annual monitoring of sediment deposits in the lower portions of the tributaries is needed to determine the storm conditions under which substantial tributary sediment is delivered to the mainstem Snake River and, from this information, the frequency, composition, and magnitude of this sediment supply.

(2) Upstream sediment supply. Appropriate mitigation strategies require an improved estimate of the magnitude of the interrupted Snake River sediment supply relative to the remaining sediment supply below the HCC..

- (a) A more detailed survey of all three HCC reservoirs is needed. Comparison of the new survey with the previous survey will provide a more accurate estimate of recent total sedimentation.

(b) A new, high-resolution topographic map of the pre-dam valley topography should be developed from historical aerial photographs. Comparison of modern surveys with a more accurate pre-dam topography will provide more a accurate estimate of the total sedimentation since construction of the HCC.

(c) Detailed mapping, surveying, and sampling of sand and gravel deposits in RM 310-340 in Brownlee Reservoir. This is the likely depositional location of the sediment delivered by the Snake River. Of particular importance is locating, mapping, surveying, and sampling of deposits of sand (and gravel). These deposits can be localized but voluminous and an accurate estimate of their volume requires first that their location and extent be identified using a broader survey, followed by a systematic sampling within all areas of significant deposition. Reservoir drawdown may be useful for these surveys.

(d) Suspended sediment sampling should be reestablished at the Snake River Weiser gage. Sampling should be weekly, increasing to daily during periods of flow greater than a threshold producing large transport rates (e.g. 25,000 ft^3/s). Bed-load sampling should be initiated on the same schedule. Sediment sampling at Weiser provides a check on estimates of the volume of sediment deposited in the reservoir.

(3) Suspended and bed-load sediment sampling should be initiated at a section on the Snake River toward the downstream end of Hells Canyon, immediately above the Imnaha River confluence. Sampling should be weekly, increasing to daily during periods of flow in excess of 25,000 ft^3/s. Bed-load sampling should be initiated on the same schedule. Sampling at the downstream end of the Canyon provides information on the rate of sediment evacuation from Hells Canyon and is needed to balance the sediment budget.

(4)Sediment budget. Estimates of the local and upstream sediment supply {(1) and (2) above} and sediment discharge from Hells Canyon {(3) above} are combined with estimates of sediment lost from Hells Canyon sand bars and spawning gravels in a complete sediment budget. By developing reliable estimates of all inputs, storage, and outputs, accuracy of the estimates can be evaluated and the relative magnitude of different sediment sources can be reliably determined.

Sand Bars

Since IPC does not question the historical record of sand bar change in Hells Canyon, the focus on future studies should be to link the existing characteristics of sand bars to current dam operations. Regular measurements of scour and fill, grain size, and bar topography should be made at approximately 12 eddy bars in Hells Canyon representing a range of river locations. Surveys should be conducted before and immediately after high flows each Spring.

Such a monitoring program is essential in determining changes in one of the critical natural resources of Hells Canyon. The value of this monitoring program will increase in value with time and the effects of future floods can be linked with sediment transport during floods. A similar program in Grand Canyon is now one of the most important metrics of ecosystem health interpreted by river managers.

Bed Mobility

If spawning gravels in Hells Canyon are occasionally mobilized, then they are transported downstream at some rate, and their maintenance requires an upstream supply. Under post-dam conditions, this supply must come from the local tributaries. Entrainment estimates based on flow models and specified values of the entrainment threshold simply cannot provide reliable estimates of spawning gravel behavior. The only real option for understanding spawning gravel entrainment and transport is to directly observe their motion in the field. This may be accomplished by marking grains within the spawning gravel area, or by placing marked or distinctive grains in the bed. By carefully surveying the locations of the marked grains, it is possible to return to the site after a high flow and deterusing a large number of tracer gravels or direct measurement of transport rates will be needed to assess the transport rate and resupply of the gravels.

Independence and Peer Review

All future work should be subject to rigorous, independent peer review. Review is needed not only for the completed work, but also for the study design prior to initiation of the work. Further, we find the presentation of facts and conclusions in the existing IPC reports to be so conspicuously biased toward a finding of no impact that we strongly recommend that future studies should not be conducted solely by IPC, or under their substantial direction. Rather, an externally reviewed study plan should be used to define specific projects that should be conducted by independent contractors, or by a fully collaborative agency/IPC team. The resulting work products, once independently reviewed, would then provide the information necessary for informed decisions about protecting the outstanding resource values in Hells Canyon.

The most enlightened management program would involve a federally administered adaptive management program in which all interest groups concerned about the Snake River in Hells Canyon would jointly administer a monitoring program. Findings of this program would be used to revise dam operations in ways that increase the potential of restricting future resource damage, and perhaps facilitate rehabilitation of the river ecosystem.

<u>10.0 Considerations for future dam operations to protect the sediment resources of Hells Canyon</u>

The primary sediment source for both sand bars and spawning gravels is now the tributaries below the HCC. As suggested in the IPC report, it is likely that these sediment inputs are very strongly episodic. Much of the time, the tributary streams transport little or no sediment and, when they do, much of this sediment may be temporarily stored in the tributary valley immediately above its confluence with the Snake River. Sediment delivery to the mainstem may occur predominantly during very large, rare floods, such as occurred in early January 1997. This suggests that sediment resources in Hells Canyon may experience “boom and bust” cycles in which long periods, possibly decades, of negligible sediment supply lead to progressive loss of sand bars and embeddedness of spawning gravel deposits, only to be briefly rejuvenated by significant sediment input from the local tributaries. If this is the case, protection of the canyon’s sediment resources may be best achieved by responding effectively to the episodes of local sediment supply. For example, a large, short dam release immediately following a major tributary flood may allow a portion of the tributary-derived sand to be stored in high elevation beaches before it is evacuated from the canyon by normal dam operations. If spawning gravel transport is found to be substantial, then reservoir operation may need to be revised in an attempt to reduce peak flows in the river (e.g. by drawing down HCC and upstream reservoirs to the maximum extent possible prior to anticipated runoff events). Determination of the efficacy of such plans requires an understanding of the tributary sediment supply—its magnitude, timing, and location—and the dynamics of sand and gravel deposition within the mainstem. Any such predictions will have considerable uncertainty, such that an adaptive management approach will be needed in which the effects of management actions are predicted, evaluated, and revised.

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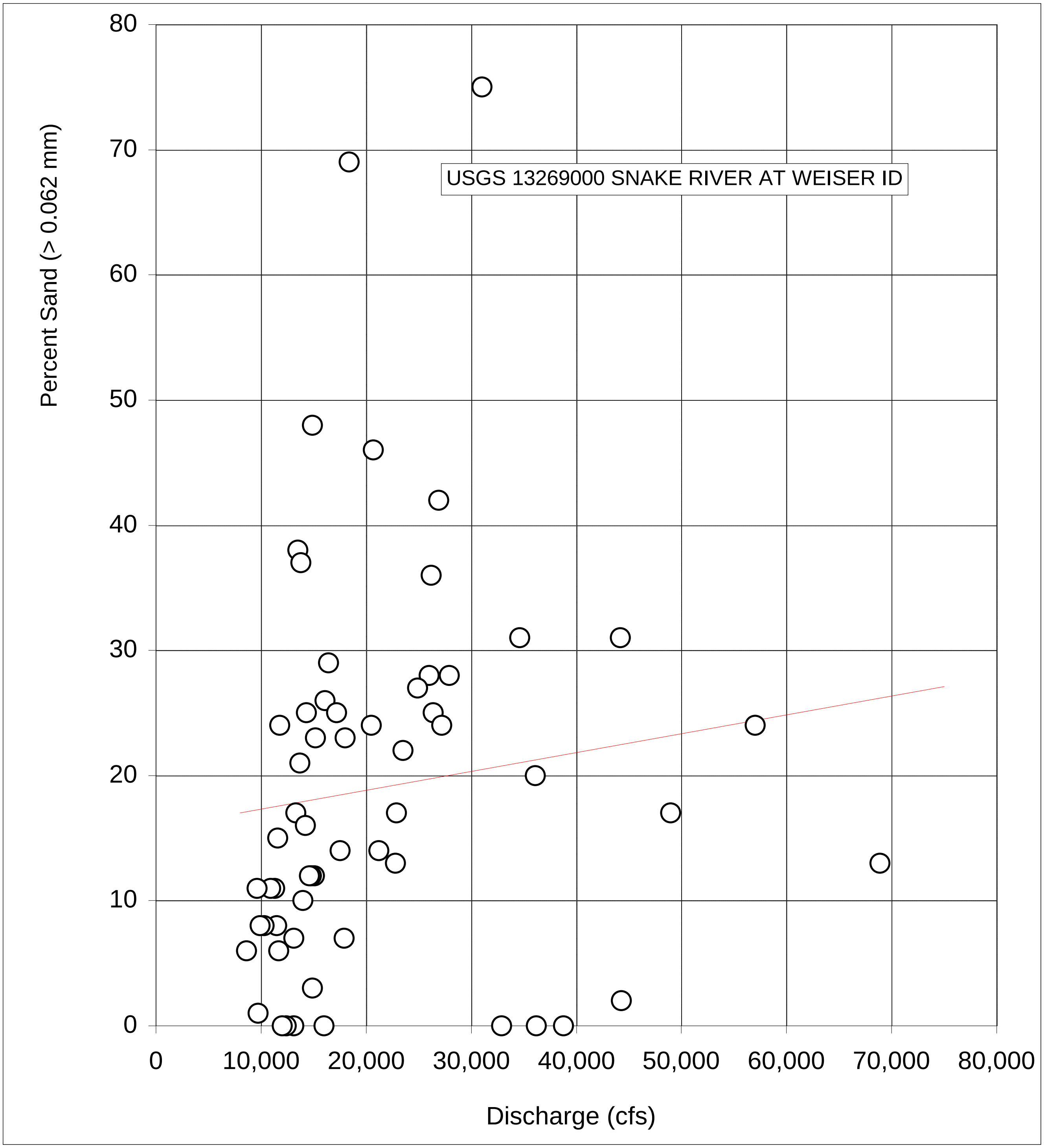

Figure 1. Percent sand in suspended sediment samples, USGS gage Snake River at Weiser ID.

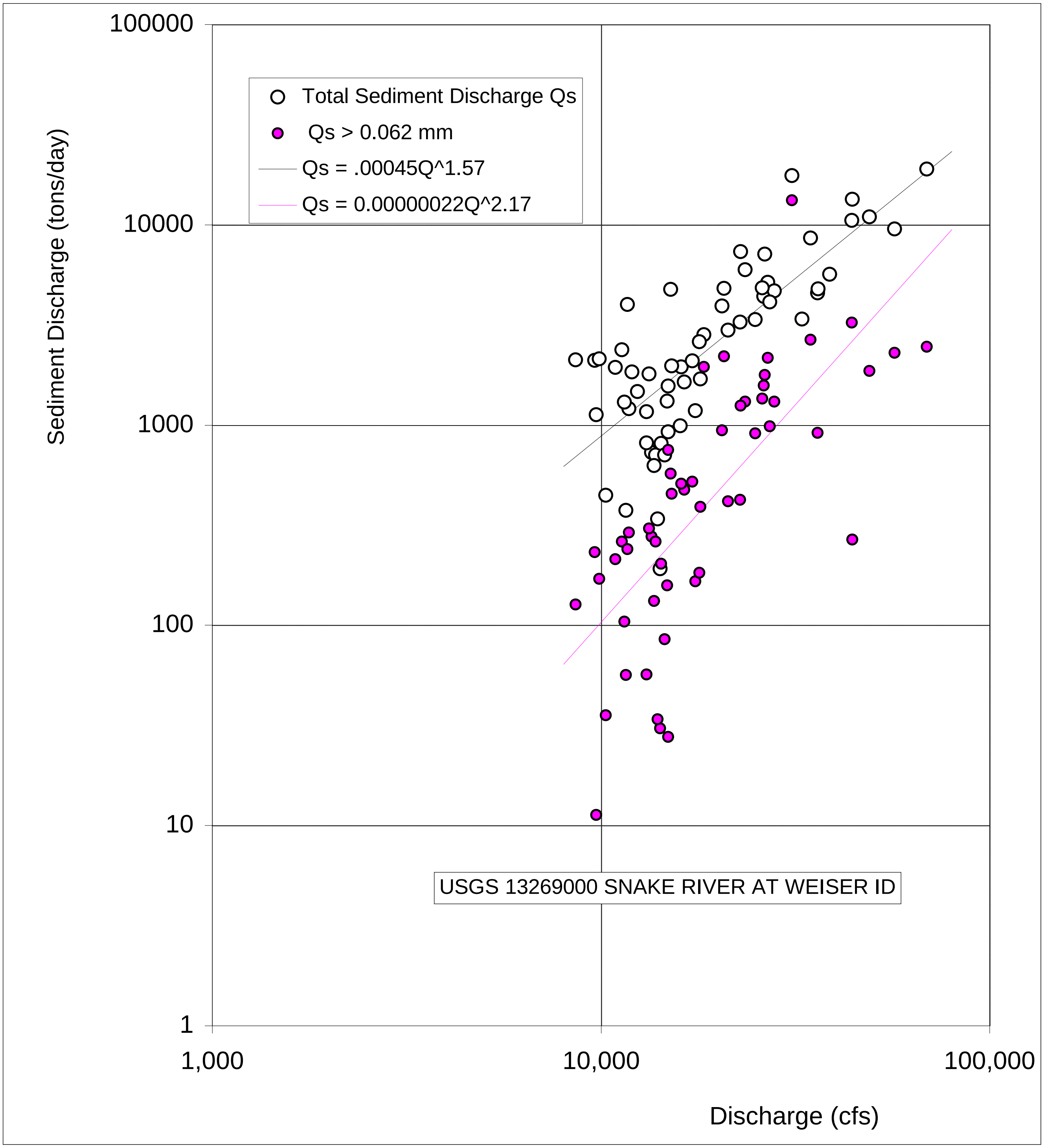

Figure 2. Sediment rating curves, USGS gage Snake River at Weiser ID.

Table 1. Sites used in IPC aerial photograph analysis cross-referenced to sand bars identified by Grams (1991).

IPC study site by River mile	Match to Grams (1991) bar	1964 to 1990 change from Grams (1991)
229.8	Johnson Bar (R)	> 50% decrease
227.5	Pine Bar (R)	small decrease
222.4	Salt Creek Bar (L)	no significant change
216.4	Fish Trap Bar (L)	no significant change
208.3	Jones Creek (R)	> 50% decrease
204.3	(not identified)	--
201.1	channel margin (R)	> 50% decrease
196.8	(not identified)	--
193.8	reattachment bar (L)	entirely eroded
192.4	China Bar (L)	no significant change

Appendix A: Geomorphic Review Questions Provided by Craig Kendall

10. Is the effect of the HCC project on resources of concern adequately addressed? (i.e. are the effects of current and proposed ramping rates on beach erosion addressed and is the resulting conclusion accurate?).
11. There is concern that the reports focus on the "Big Picture" (i.e. the geologic factors which formed the Canyon) tends to minimize and obscure potential project-related effects such as beach erosion.
12. Is the method for determining influx of sediment into Brownlee adequate given that there is no analysis of bedload movement and no sediment budget was constructed above and below the project.
13. Are conclusions in the documents accurate for identifying sediment transport flows and the lack of bedload movement upstream from Brownlee Reservoir?
14. In general, are the equations and analysis used in the IPC documents valid?
15. IPC concludes that the project has no effect on beach erosion since the material trapped in the upstream end of Brownlee Reservoir is not from the same parent geology as that found in the beaches in the HCW&S River. This was based on a limited number of samples and did not include any sampling in sediment plumes/deltas in tributaries to Hells Canyon Reservoir and Oxbow Reservoir which may be from the same parent material. Is the scope and scale of sediment sampling in Brownlee Reservoir adequate and should the other reservoirs be evaluated as well?
16. Is the "slug of sediment" theory valid since there was no data to support it?
17. In their information presentations, IPC has discounted the Grams and Schmitt studies on beach erosion and concluded that based on their own three consecutive years of trend data the beaches in HCW&S River are stable. Is this valid?
18. What (if any) additional studies or analysis are needed to address USFS concerns (primarily beach erosion)?

Appendix B. Response to Specific IPC Conclusions

Specific conclusions are presented in list form in several places in Parkinson (2002). Although we address these points in our review, we also include point-by-point comments on these conclusions.

B1. Comments on Executive Summary Conclusions

In the Executive Summary (p. 2), Parkinson et al. (2002) present eight conclusions in a bulleted list.

• The storage capacity of the HCC is only about 10% of the average annual volume of the Snake River as given by calculated inflow to Brownlee reservoir. Therefore, the HCC has a relatively small effect on the hydrograph downstream of the complex.

Comment: Although the storage capacity of the HCC has a modest effect on downstream flow, it has changed flow through the Hells Canyon. Grams and Schmidt showed that …

• Changes in the river observed since the construction of the HCC (such as shrinking sand beaches) may be caused by human activity higher in the Snake River Basin since the mid-1800s and not by construction and operation of the HCC.

Comment: While sand supply from the entire watershed may have peaked and decreased over the past century, its connection with shrinking sand bars following completion of the HCC is tenuous, undemonstrated, and avoids the immediate issue of the quantity of trapped sediment relative to downstream supplies and sediment loss from Hells Canyon. We think it is likely that most of the fine sediment eroded from the watershed in the 19th and early 20th century either passed through the system in a matter of years or become sequestered in overbank and bar deposits, where it still remains. The sand bars in Hells Canyon are delicate and dynamic features, representing temporary and live storage of a portion of the sand delivered to the canyon. If a decrease in sand supply over the past century has contributed to shrinking the sand bars, it is curious to argue that completely eliminating the upstream sediment supply (due to storage in HCC) would be of little consequence. In any event, an unambiguous conclusion in this regard requires reliable quantification of the sources of sand to the canyon, which IPC has not provided.

• The transport competency of the Snake River upstream of the HCC is insufficient to mobilize and transport materials such as those found in the riverbed of the Hells Canyon reach. Therefore, no supply of bed materials would be available from sources upstream of the HCC under historical hydrological conditions.

Comment: A clear distinction needs to be made between sediments of different sizes. It is likely that this statement is correct regarding coarse gravel and cobble, but not for sand and fine gravel. Coarse cobble and boulders found in deeper parts of the Hells Canyon stream channel may be predominantly supplied from local tributaries. Sandbar caliber sediment *is* being delivered in significant quantities by the Snake river above the HCC. This sediment discharge has been measured by the USGS. The analysis conducted by IPC is not adequate to reliably judge the supply under modern conditions of fine to medium gravels used for spawning.

• Less than 4% of the sediment trapped in Brownlee Reservoir (the uppermost dam in the HCC and the first of the three constructed by IPC) is larger than fine sand. All of the features of interest downstream are largely made up of sediments larger than fine sand.

Comment: This argument diverts attention from the main point. It is not the *percentage* of coarser sediment delivered to Brownlee Reservoir that matters, buts its actual quantity and how that quantity compares to sediment sources below the HCC. We find that the estimate of sediment stored in Brownlee Reservoir is unreliable and that further study is required to obtain a reliable estimate. We also find that the proportion of sand delivered to Brownlee Reservoir is more likely approximately 22%, based on USGS measurements at Weiser. Drawing the grain size boundary at "larger than fine sand" may also be misleading. This choice is based on the assumption that the sediment features found in Hells Canyon *under present conditions* are representative of those found under predam conditions. The impact of the HCC on sediment resources in Hells Canyon must be referenced to predam conditions, not to conditions some 40 years later. The data presented by IPC suggests that the grain size of predam sand deposits may in fact be finer than observed under present conditions.

• The trapping of fine sediments in Brownlee Reservoir has not caused the downstream river to become more "sediment hungry" because the size and concentration of these sediments has no effect on transport capacity in the Hells Canyon reach of the Snake River.

Comment: This statement reflects a misunderstanding of the concept of transport capacity. Transport capacity is a measure of a river's ability to carry sediment and depends primarily on the channel geometry and flow rate. The presence or absence of an upstream sediment supply does not alter a river's capacity for transporting sediment. The term "sediment hungry" refers to a condition in which sediment is supplied to a reach at a rate that is smaller than the river's capacity to transport sediment. It is likely that the Snake River in Hells Canyon has always been "sediment hungry" with respect to sand and finer gravels, meaning that the river could carry additional sediment without a substantial change in its geometry and that the sediment stored in the Hells Canyon will be found in particular locations that provide some protection from the flow. There can be no doubt that the HCC has reduced the upstream sediment supply (it has essentially eliminated it) and that, therefore, the amount by which the transport capacity exceeds the sediment supply has increased. In that sense, the river is indeed "more sediment hungry". The appetite of the river is, however, not the most relevant concept for judging the impact of the HCC on sediment resources in Hells Canyon. Eliminating the upstream sand supply has reduced the sand transport rates and sand concentrations in the flow through Hells Canyon. Current research on sand deposits in canyon rivers indicates that a reduced sand concentration in the river flow is a direct cause of reduced sand bar size.

• Because the basic form and character of the river were established under vastly higher flow conditions, the bed and bank materials provide extremely limited opportunity for river movement.

Comment: Again, an important distinction must be made for sediments of different size and location. This statement is true, for example, for boulders found in deep parts of the river channel in Hells Canyon. It is demonstrably *not* true for sand bars, which have eroded considerably since closure of the HCC.

• Continuing supplies of sands, gravels, and cobbles from local sources below HCD have not been affected by the construction and operation of the HCC.

Comment:

• Human activities in and above the Hells Canyon area, such as mining and grazing, modified hill slope processes from the mid-1800's to the mid-1900s. These activities probably introduced an unusually large sediment supply to the river that decreased as the activities that introduced them also decreased. This "slug" of sediment may be working its way out of the Hells Canyon system.

Comment: An increase in watershed sediment supply may well have occurred in the 19th and early 20th centuries. We find it improbable that a sand "slug" would be gradually moving through the high-energy environment of the Hells Canyon. It is more likely that 19th century sediment from higher in the basin has been long sequestered in bars and floodplains and upper basin reservoirs or moved through the Hells Canyon long before the HCC was completed. The relative proportion remaining in the watershed, the locations of these deposits relative to existing dams, and the rate at which these deposits release sediment back in to the stream are largely unknown and any conclusions in the absence of this information are entirely speculative. The impact of the HCC on Hells Canyon sediment resources must be addressed by solid estimates of the sediment supply lost to the HCC, in comparison to the amount supplied by local tributaries below the HCC and the amount of sand lost by sand bars.

B2. Comments on Sediment Supply Conclusions

In Section 10.4, Parkinson et al. (2002) present six conclusions in a bulleted list on p. 83.

- There is no evidence that Brownlee Reservoir (the uppermost reservoir in the HCC) has trapped significant quantities of sediment in sizes that could affect any of the important resources. More than 96% of the material trapped in Brownlee Reservoir is smaller than fine sand and therefore smaller than the majority of the material found in the sandbars in Hells Canyon.

Comment: This statement is incorrect or misleading in three ways. First, there *is* clear evidence of an upstream supply of sediment of relevant sizes. The reservoir data reported by IPC provides evidence of this, although we find the data are inadequate to provide a reliable estimate. The USGS record of water and sediment discharge at Weiser provides clear evidence of the quantities of sand delivered to the HCC by the Snake River. Second, to cite the estimated delivery of sediment to Brownlee Reservoir as a percent is misleading. What is relevant is the *quantity* of sand that is trapped in the reservoir *in comparison to* the quantity of sand that has been lost from the Hells Canyon sandbars. A rough estimate is that the annual rate of upstream sand supply (now trapped within the HCC) is *at least* ten times the rate at which sand is lost from the sandbars in Hells Canyon. This is significant. Finally, using the material found in Hells Canyon *today* as the basis for evaluating the impacts of the HCC on downstream sand resources avoids the probable adjustments in sandbar composition over the postdam period.

- The Snake River upstream of the HCC is incapable of transporting sediment of the size found in the riverbed in Hells Canyon under current hydrological conditions.

Comment: A distinction must be made regarding the caliber of sediment in question. If the focus is the coarse cobble and boulders found in deeper parts of the Hells Canyon stream channel, it is likely that little would be supplied from upstream under current conditions. If the focus is sandbar caliber sediment, it is clear that Snake River above the HCC *is* delivering significant quantities of this sediment. This sediment discharge has been measured by the

USGS. If the focus is on fine to medium spawning gravels, the analysis conducted by IPC is not adequate to reliably judge the supply under modern conditions.

- There are tributaries in Hells Canyon not affected by the HCC that supply sediment in the size range useful for maintaining the sandbars and gravelbed spawning sites in Hells Canyon.
- There is clear visual evidence that many of these tributaries have supplied sediment to the Snake River in Hells Canyon in recent years under current hydrologic conditions

Comment: We find that assumptions and methods used by IPC have led to a gross overestimate of the amount of this sediment supply. A reliable estimate of tributary sediment supply is not currently available. Further, the timing of tributary sediment delivery is an important and unresolved issue. Local tributaries below HCC do deliver sediment to the mainstem Snake River. This supply was probably significant during the winter 1997 floods. Evidence presented in the report suggests that these tributaries may contribute very little sediment to the mainstem Snake except during such large, rare storms. If significant tributary sediment supply occurs rarely (with a recurrence interval of many years or decades), the sediment resources in Hells Canyon may show short term benefit following major tributary floods, followed by decline under conditions of negligible sediment supply. We recommend that a sound estimate of the local sediment supply be made using sedimentation observations in smaller dams on tributaries and sedimentation within Hells Canyon reservoir. This information is needed to develop a working knowledge of the Hells Canyon sediment system, which can serve as a base for recommendations regarding operations of the HCC.

- Mineralogical composition of bed-material sediments suggests that these sediments are of local Hells Canyon origin. The lack of minerals characteristic of the upper regions of the Snake River Basin suggests that riverbed materials in the Hells Canyon reach were not transported from upper parts of the basin.

Comment: The data presented do *not* show distinctions between upstream and downstream. The "minerals characteristic of the upper regions of the Snake River Basin" are not evident in either upstream or downstream samples. Further, it is likely that the Hells Canyon sediments examined were *post-dam* deposits. If this is the case, a finding that they are of local origin has little significance because they were deposited after the upstream supply of sediment was cut off.

- There are data from the early 1900s (well before the HCC complex was built) through the present time indicating that the Snake River upstream of the HCC is highly stable, with limited movement of the bed material. More recent data from downstream of the HCC indicate similar findings.

Comment: Upstream of the HCC, the issue is the quantity of sediment supplied. The USGS observations at Weiser indicate the sediment discharge of sand. The IPC analysis is insufficient to document the transport of gravels suitable for spawning. A stable cross-section (in the sense that it does show substantial scour or aggradation) is not, of itself, an indication of small sediment transport rates. Downstream of the HCC, the stream channel is canyon bound and coarse bedded and clearly will not show large changes in its morphology. This, however, is not a particularly relevant point. The sediment resources of interest—sandbars and spawning gravels—are small, delicate, and typically found in protected areas of the channel. These resources are dynamic, meaning that the sediment is transported, and indicating that these features are sensitive to the availability of an upstream supply of sediment.

5. HYDROLOGY, MORPHOLOGY, AND SEDIMENT DYNAMICS DOWNSTREAM FROM HELLS CANYON DAM

5.1 Stream Flows

5.1.1 Outflows to Hells Canyon

The section summarizes the findings of another report (Idaho Power Company, 2001, Project hydrology and hydraulic models applied to the Hells Canyon Reach of the Snake River). IPC's decision to cross-section various reports greatly hampers the review of the substance of the science and engineering, because the reader is forced to continually refer to other documents and to independently evaluate whether results from a related study have been fairly described in some other report.

The section summarizes the salient points about Hells Canyon Dam releases downstream. Discharge between 9000 and 13000 ft^3/s are maintained between mid-October and mid-December "for spawning." Downstream flows are maintained above spawning flows until smolts emerge in May or June, and diurnal stage changes exceed 2 ft.

The difference between the mean annual discharge of the Snake River measured at Hells Canyon Dam (20,875 ft^3/s) and Anatone (36,635 ft^3/s), minus the inflow from the Imnaha, Salmon (11,270 ft^3/s), and Grande Ronde Rivers is 875 ft^3/s, which IPC estimates to be the total inflow from ungaged tributaries in Hells Canyon. This amount is a 4% increase from the mean annual flow at Hells Canyon Dam. The total increase caused by the Imnaha, Salmon, and Grande Ronde Rivers is 14,885 ft^3/s, which is a 71% increase above the mean annual discharge at Hells Canyon Dam. Most of this increase is due to inflow from the Salmon River

Thus, the Salmon River causes a significant hydrologic change in the Snake River and it is appropriate to distinguish changes to the Snake River caused by Hells Canyon Dam upstream from the Salmon River from those downstream.

5.1.2. Comparison of Pre- and Post-HCC Stream Flows

This section points out that the analysis of hydrologic changes conducted by Grams (1991) and by IPC are in agreement: The HCC causes relatively little change in the downstream hydrology. Grams (1991) determined that the 10-yr flood at Hells Canyon Dam had increased 4%, from 75,000 to 78,000 ft^3/s, that the mean annual flood had not significantly changed, and that the shape of the mean daily discharge flow duration curve had not changed significantly.

IPC supplemented this analysis by using the Indicators of Hydrologic Alteration (IHA) software to determine changes in the mean daily discharge and to compare Present Operations with a Run-of-the-River Scenario prepared by IPC. The primary differences between the Present Operations Scenario and the Run-of-the-River Scenario are in the months described in Section 5.1.1 when natural inflows are altered for flood control or to facilitate sqpawning success downstream.

IPC's analysis of mean daily discharge data using the IHA software is of limited value because dam releases vary hourly in response to power production needs and these flow attributes were not evaluated. Accurate analysis of flow characteristics of the Snake River demands that flow duration characteristics, as well as others evaluated by the IHA software, be based on instantaneous discharge data.

5.2 Morphology

This short section characterizes the Snake River downstream from Hells Canyon as an F-1 type stream. Given the abundant physical measurements of Hells Canyon and the Snake River, no additional insight regarding the character of the river is gained by knowledge of this classification.

IPC refers to Hells Canyon as the river reach downstream from Hells Canyon Dam. Vallier (1998, p. 6-7) reviews nomenclature regarding the term Hells Canyon and points out that the physiographic feature is considered to have different lengths by different individuals. Vallier (1998) considers Hells Canyon to include the segment of the Snake River between the Oxbow and the mouth of the Grand Ronde" and he calls this "a liberal definition" based primarily on a common geologic history. He also states, "If I were to base my definition only on physiography, I would limit Hells Canyon to that segment of canyon between Kinney and Sheep Creeks". Kinney Creek is located approximately 10 miles upstream from Hells Canyon Dam and Sheep Creek is located about 18 miles downstream from the Dam, and Hells Canyon is approximately 28 miles long based on this criteria. Approximately 36% of this length has been inundated by the HCC.

The section notes that "the floodplain is extremely limited" and "interaction between the river and its bed and banks is largely limited to near-river areas that can be mobilized by the flow, such as bars, islands, terraces, and fans." This characterization is accurate, however, the important point about assessment of the effects of dam operations on the downstream river is not the proportion of the total bank that can be reworked and maintained by river flows, but the changes that have occurred in these reaches, regardless of their absolute length. It might be argued that the small proportion of the total river length that is comprised by sand bars or terraces makes those deposits more important from an ecological or recreational perspective.

5.2.1 Nearshore Characterization

IPC reports that 54% of the river banks are hillslopes. Bars increase in number in the downstream direction, and the average for the reach between Hells Canyon Dam and Asotin is 18 to 20 %. Debris fans average 18 % of the river banks and a reportedly "evenly spaced."

5.2.2. Channel Morphology

5.2.2.1. Valley Segment Morphology

IPC proposes that the study reach be divided into three segments based on differences in channel slope, which is 0.002 in the upper segment and 0.0007 in the lower segment.

Again, IPC emphasizes the narrow confinement of the Snake River in its canyon. While this confinement is a distinctive attribute of the study area, it merely serves to emphasize the importance of eddy bars, channel-margin deposits, terraces, and gravel bars in the riverine ecology and recreational uses of the canyon.

5.2.2.2. Reach-scale Morphology

5.2.2.2.1. Sinuosity and Confinement

IPC proposes a subdivision of the three valley segments into a series of 12 reaches, based on differences in sinuosity and confinement. It would have been helpful had IPC chosen to compare and contrast its classifications with those proposed by Vallier (1998), who proposed his own scheme for recognizing sections of the river with common attributes. It is not clear that IPCs classification is an improvement on previously published efforts, although certainly the river morphology data collected by IPC is superior to that available to Vallier (1998).

5.2.2.2.2. Reach Type

Miller at al. (2002, p. 5-9) find that the Snake River in the stidy area "shows the repeating sequence of pools and riffles" and that the spacing between pools typically has a value of between 5 and 10. Although observations like this are irrelevant to assessment of the environmental impacts of the HCC on downstream river resources, it is nevertheless an interesting observation of doubtful validity. Similar observations were made of the organization of the bed of the Colorado River in Grand Canyon by Leopold (1969), who argued that the Colorado River reflected self-formed attributes similar to alluvial rivers. IPC implies the same for the Snake River. In Grand Canyon, it is now recognized that the distribution of shallow and deep sections of the river are determined by the locations of tributary debris fans and the related distribution of pools, eddies, and gravel bars that comprise the widespread attributes of fan-eddy complexes (Schmidt and Rubin, 1995, Grams and Schmidt, 2000).

5.2.2.2.3. Channel Units

This section reviews findings from detailed mapping of channel units, similar to studies conducted on much smaller streams in the western U. S. This information is interesting to the geomorphologist who works in debris fan-dominated canyons but is of little relevance to assessment of the impact of the HCC on downstream river resources.

IPC reports that the frequency of debris fans in the upper and middle valley segments is approximately 3 fans/river km, which is a higher frequency than in most parts of the Colorado River in Grand Canyon (Schmidt et al., 1999). Thus, the role in debris fans and in fan-eddy complexes is more important here. IPC would have done well to have characterized the river using the fan-eddy classification scheme that is appropriate to a river of this organization, rather than apply a scheme of more relevance to small mountain streams.

5.2.2.2.4. Pools

This section characterizes pools and their residual depths. This information is interesting to the geomorphologist who works in debris fan-dominated canyons but is of little relevance to assessment of the impact of the HCC on downstream river resources.

5.2.2.3 Hydraulic Geometry

This information is interesting to the geomorphologist who works in debris fan-dominated canyons but is of little relevance to assessment of the impact of the HCC on downstream river resources.

5.3 Sediment Dynamics

5.3.1 Potential Sediment Sources

5.3.1.1 Local Tributaries

This paragraph reminds the reader that the local tributaries to the Snake River downstream from the HCC "is significant." Although we disagree with the IPC's estimates of the magnitude of sediment delivery from these tributaries, as described in our report, we agree with IPC's assessment of the importance of these tributaries to river management. Regardless of the magnitude of the sediment delivery, these tributaries are the only source of sediment to the Snake River upstream from the Imnaha River. Thus, it is essential to understand the magnitude and timing of these contributions if the "benefits" of this sediment can be maximized by operations of Hells Canyon Dam.

5.3.1.1.1 Short-term Quantitative Sediment Yield Estimates

This section summarizes the estimates of sediment delivery made by Parkinson et al. (2002). The cross-referencing between the Miller et al. (2002) and Parkinson et al. (2002) is poor here and limits the ability of the external reviewer to evaluate the estimates of IPC. In this case, IPC does not reference the source of the numbers reported and IPC assumes that the reviewer will find the computations elsewhere. Or perhaps IPC hopes that the external reviewer will not identify and evaluate the methods by which these estimates are made. Whatever the case, these estimates are made without discussion of the accuracy or precision of these numbers. Instead, IPC reports these numbers as if they were true when, in fact, they are highly speculative and are clearly a gross overestimate of the amount of sediment entering Hells Canyon downstream from the dams.

IPC reports the following estimates of sediment yield downstream from the HCC:

	Drainage area, in square miles	Sediment yield, in tons/square mile/year	Sediment yield, in cubic yards/acre/year	Annual sediment delivery, in tons/year
Average sediment yield from 17 small tributaries to the Snake River	304	28,100	32.5	8.5
Other tributaries	191	28,100	32.5	5.4
Hillslopes directly sloping to Snake River	53	28,100	0	1.5
				15.4, of which 6.3 million tons/yr is gravel between 50-150 mm and 2.3 million tons/yr is sand

IPC is aware of the significance of these estimates, and states that "this estimate is about 5 times higher than the annual supply of sediment that has been retained by Brownlee Reservoir since 1958." Indeed, the large magnitude of these numbers demands that the estimates be based on more than uncalibrated engineering transport calculations.

IPC states that the combined sediment delivery from all tributaries to the Snake River is 15.1 million tons/year, however the product of 28,100 tons/square miles/year and 495 square miles (the total basin area of tributaries) is 13.9 million tons/year, which is 8% less than IPC's estimate.

5.3.1.1.2 Long-term Sediment Yield Considerations

Although the findings of Kirchner et al. (2001) are of interest to geomorphologists, they have little relevance here. Kirchner et al. (2002) compared short- and long-term sediment yield estimates, all of which were based on detailed field studies and sophisticated watershed modeling. These studies conducted in central Idaho did not utilize the uncalibrated formulae that result in the unrealistically high estimates made by IPC.

Observations of debris flow deposits and the locations within tributary drainages where these sediments are stored are of interest, and debris flows may be a major unquantified mechanism by which sediment is delivered to the Snake River. IPC would be well-served to undertake further studies to quantify this contribution.

<u>5.3.1.2</u> <u>*Hillslopes*</u>

5.3.1.2.1 Short-term Quantitative Sediment Yield Estimates

IPC assumes the same sediment yield rate to the Snake River as for the tributaries basins without any field based quantitative estimates to support this value.

5.3.1.2.2 Long-term Sediment Yield Considerations

It is helpful to be reminded that catastrophic geomorphic events can occur in Hells Canyon, and when they do, the USFS, ACoE, and IPC will undoubtedly be faced with the need to reconsider how the HCC dams release water downstream so as to achieve whatever management goals will be established at that time in response to a large natural catastrophe.

IPC provides geographic analyses of the distribution of slope steepness within the tributary basins, as well as the distribution of slopes with rock varnish (which is taken to indicate the absence of significant slope movement in the past 1000 yrs.). These data indicate that the hillslopes of Hells Canyon are likely to have high erosion rates. The point, however, is whether IPC's estimate of 28,100 tons/square mile/year is remotely realistic, and why such a rate only applies to that part of Hells Canyon downstream from Hells Canyon Dam and not to the areas of similar physiography and geology that flow directly into Hells Canyon Reservoir. The field observations are important and useful, but are unrelated to the magnitude of the engineering-based estimates of Parkinson et al. (2002), which are impossibly large.

5.3.1.3 Riverbed Materials

The primary finding of IPC is that "isolated pockets of bed material move under the flows currently experienced in this reach, but the majority of the bed appears to be stable." Since this finding references Parkinson et al. (2002), we refer to our review in the main part of our report concerning the inaccuracy and imprecision of this finding.

Miller at al. (2002) find evidence of suturing between particles and existence of rock varnish are evidence that parts of the bed have not moved in a very long time. In other canyon river systems where there is abundant gravel such as the Grand Canyon, historical studies show that large thickness of sand were once abundant as a veneer over gravels and that fine gravel and sand is also intermittently stored in intertices of gravel. Thus, the observations about the large framework gravels of Hells Canyon does not demonstrate that modern observations reflect pre-HCC conditions or bed conditions immediately after influx from a tributary sediment delivery event.

5.3.1.4 Riverbank Materials

Miller et al. (2002) refers to the results of a study by Parkinson et al. (2002) that erosion was measured at only 3.1% of the total shoreline of the Snake River between Weiser and the Salmon River. We are unaware of how Parkinson et al. (2002) made this estimate, but we assume this study is Holmstead (2002) which comprises Appendix E of Parkinson's report. In light of the fact that the majority of Homstead's study area was the shoreline of the HCC reservoirs, the reporting of the total percentage of eroding bank is irrelevant to the issues of river management in Hells Canyon.

Clearly, the proportional contribution of sediment to the Snake River flux supplied by eroding banks is small compared to influx from tributaries. However, the importance of the issue of terrace erosion in Hells Canyon is not the quantity in relation to other sediment sources. Instead, the importance of direct measurements of terrace erosion is whether such erosion threatensvital resources of the HCNRA and if this erosion is unusual or accelerated and is related to operations of the HCC.

Miller at al. (2002) summarize the findings of Grams and Schmidt (1999b) who measured erosion of terraces at the Tin Shed site. IPC does not question the historical sequence and magnitude of geomorphic change measured at Tin Shed, nor at other terrace sites measured by

Grams and Schmidt (1999a). Instead, IPC offers speculative arguments about reasons why accelerated erosion might be occurring that are unrelated to operations of the HCC. These reasons include the existence of placer mining within Hells Canyon, an activity that clearly occurred but whose influence on the geomorphology of the study area is undocumented in any quantitative way.

Grams and Schmidt (1999a, b) showed that the high floods of 1997 reached the base of the terraces at each of their measurement sites and that bank retreat occurred at those times. The finding that the high releases from the HCC caused this bank retreat is clear. No study of Grams and Schmidt (1999a, b) offer a mitigation strategy to deal with erosion during unusual floods. The point of their measurements was simply to link cause and effect, and IPC would do well to pursue a similar effort. We assume that IPC accepts the existence of high, and episodic, rates of terraces erosion in Hells Canyon. Strategies to deal with this phenomena in mitigation is a matter for a different study no yet undertaken.

5.3.1.5 Visual Analysis of Bed Materials

We review the scientific analysis and interpretation of these data in the main body of our report. We find that IPC inaccurately interprets their own data and their conclusions about the local origin of fluvial sediments is overstated.

5.3.2 Mainstem Sediment Dynamics

5.3.2.1 Sediment Supplies and Transport capacity

This section makes general comments about the implications of the steep slope and narrow canyon of the Snake River in Hells Canyon. It is true that the river has been incising into the canyon for millions of years and that the canyon is, in this sense, erosional. The section recognizes that there are isolated depositional features and that these are transitory in a geological time sense. This transitory characteristic does not make these features any less significant from a river management perspective, however.

The statement by IPC, "Both coarse- and fine-grained depositional features are likely transitory because they grow or shrink in response to both long-term tends in sediment supply and transport capacity, as well as to infrequent events that can mobilize and transport substantial sediment …" This statement is true and thus highlights the importance in understanding the linkage between the changes in the flux of sediment caused by the HCC and downstream changes in sand bars.

5.3.2.2 Sand Beach Dynamics

5.3.2.2.1 Grams Analysis

The review of some of the conclusions of the research of Grams (1991) and Grams and Schmidt (1999a) are accurate in their description of the findings of those studies.

The last sentence of the IPC section bear no significance is evaluating the applicability of those papers however. It is true that Grams (1991) and Grams and Schmidt (1999a, b) did not develop a sediment budget for the study area. The absence of such a budget, however, does not negate the accuracy of the history of bar change described by those studies.

5.3.2.2.2 IPC Analysis

This section summarizes findings by IPC concerning changes in sand bars. It is unclear what the intention of these studies since there is no discussion which seeks to link the IPC findings with those of Grams (1991) and Grams and Schmidt (1999a, b).

IPC reports on surveys and subsequent resurveys of four sand bars during the period 1997 - 1999. These four bars are the same as those surveyed by Grams and Schmidt (1999a). IPC found that these bars are composed of sand, that redistribution of sediment occurred as areas of erosion and deposition, and that coarsening occurred at Pine Bar. Ipc also reports on its inventory of bars, as determined by aerial photograph analysis, for the period 1948 – 1955.

The analysis by IPC represent a helpful addition to the work of Grams and Schmidt, but IPC fails to integrate its findings with those earlier studies. Grams and Schmidt (1999a) also resurveyed the four bars in question in 1999 and compared those surveys with ones made in 1990. Thus, they were alble top evaluate longer term trends on surface topographic change. They also found that there were local changes in erosion and deposition, and local areas of cutbank retreat at about the elevation of the maximum stage of the 1997 floods. Grams and Schmidt (1999a) speculated that the large flood of 1997 caused most of these changes. Such speculation is consistent with IPC's results.

Grams and Schmidt (1999a) also determined that there had been small degrees of change in the number of bars in Hells Canyon, based on reinventory of the bars that they had previously identified. The IPC inventory for the period 1948 to 1955 does not clarifiy or contradict any of Grams and Schmidt (1991)'s conclusions.

In general, this work by IPC does not significantly add to the understanding of the system found by Grams and Schmidt (1999). No aspects of IPCs work contradicts the earlier findings.